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AECV92-R6

REPORT TO THE CELANESE GROUNDWATER CONTAMINATION STUDY GROUP REGARDING CONTAMINANTS IDENTIFIED IN GROUNDWATERS UNDERLYING INDUSTRIAL SITES OF CELANESE CANADA INC. AND CLOVER BAR SAND AND GRAVEL LTD.

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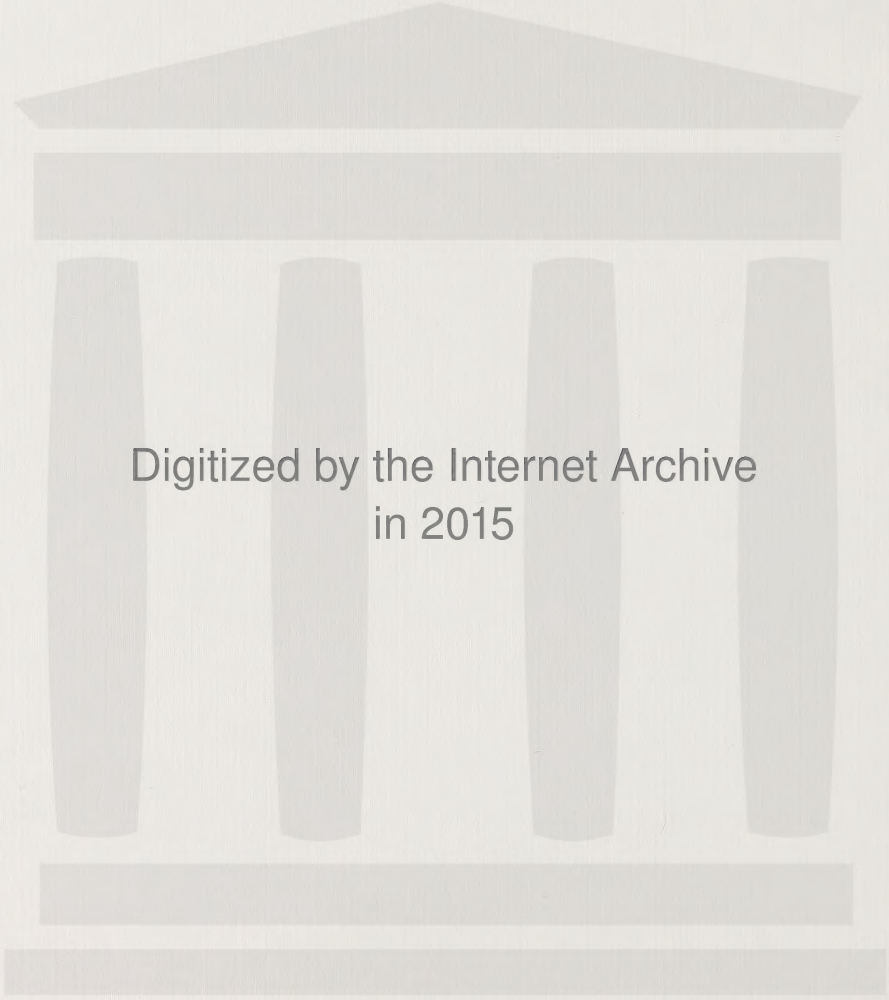

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REPORT TO THE CELANESE GROUNDWATER CONTAMINATION STUDY GROUP REGARDING CONTAMINANTS IDENTIFIED IN GROUNDWATERS UNDERLYING INDUSTRIAL SITES OF CELANESE CANADA INC AND CLOVER BAR SAND AND GRAVEL LTD.

by
M.G. PRIOR, Ph.D.
Toxicology Branch
Biological Sciences Division
Alberta Environmental Centre

October 8, 1992

DISCLAIMER

This report is a discussion of the risks that might be associated with exposure to the small number of chemicals detected in samples of contaminated groundwater. It does not address risks associated with substances present in the samples but not identified by chemical analysis. This report was presented to the clients and accepted by them as the status of knowledge on the subject in September, 1991.

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EXECUTIVE SUMMARY

In early 1982, Alberta Environment was made aware of groundwater contamination in the immediate vicinity of wastewater ponds operated by Celanese Canada Inc. In response to a Water Quality Directive, Celanese Canada Inc., implemented a groundwater study and developed plans for closure of the wastewater ponds. Concerns were raised by Alberta Environment regarding both discharge of contaminated groundwater to the North Saskatchewan River and the potential impact on the Beverly Channel aquifer. The wastewater streams within the Celanese plant were redirected into a new system, the ponds were closed and capped during 1984-85, and a groundwater monitoring program established to evaluate the natural rehabilitation of groundwater following removal of the contaminant source.

Pollution Control Division, Alberta Environment, has been responding to complaints of contaminated groundwater at Clover Bar Sand and Gravel Ltd., since 1984. In 1986 Alberta Environment met with Celanese Canada Inc., to develop a solution to contaminated groundwater seeping into new excavations at the gravel pits. Celanese has developed a system for collecting contaminated water in the gravel pit area and pumping it back to the plant and their deep disposal well. Clover Bar Sand and Gravel Ltd., has received a licence from Alberta Environment to discharge surface waters to the North Saskatchewan River.

In early 1989, representatives from Alberta Environment, Edmonton Board of Health and Celanese Canada Inc., met to review progress of groundwater reclamation and to discuss related impacts on the sand and gravel operation. Groundwater monitoring showed that TOC (total organic carbon) levels in all wells have been declining since May, 1983, although TOC levels were still very high. The natural cleanup trend was considered to be good, but predictions could not be made regarding the time required to achieve total cleanup, that is, a return to background levels. Celanese Canada Inc., will continue to intercept and pump contaminated groundwater back to their deep disposal well, to construct additional monitoring wells, to assess the extent of the contaminant movement in the gravel pit, and to report to Alberta Environment when this investigation has been completed. Clover Bar Sand and Gravel Ltd., is planning to move into more contaminated areas on their property.

In response to concerns for the adverse effects of chemicals on-site and moving off-site, a toxicological assessment was developed at the request of Alberta Environment, Wastes and

Chemicals Division, for the Celanese Groundwater Contamination Study Group (consisting of staff from Alberta Environment, Edmonton Board of Health and the Alberta Environmental Centre). It should be recognized that risk assessment is not a precise process, and deals in probabilities not certainties. Further, that there is no such thing as "completely safe" or "risk free".

Six observations are made:

1. Contamination of groundwaters, sands and gravels will likely persist for a number of years. This will affect all ameliorative measures. Removal of the source or sources of the contamination or containment of the contaminated groundwaters would shorten the period of seepage of contaminated groundwaters from Celanese Canada Inc., into the North Saskatchewan River, and reduce adverse effects on the operation of Clover Bar Sand and Gravel Ltd.
2. The presence of a mixture of potential human carcinogens, toxic and potentially toxic chemicals, and unidentified substances in the groundwater, sands and gravels represents an *involuntary* risk to exposed people and animals. These exposures may be at the workplace or away from the workplace.
3. Some 96 to 83 per cent of the chemical contamination in the groundwater remains unidentified. Risk assessment for the complex chemical mixtures associated with these industrial sites is much less definite than that for a single compound.
4. The effects of contaminated discharge on the North Saskatchewan River have not been characterized.
5. The Fisheries Act (Section 33(2)) specifically prohibits the deposit of a "deleterious substance" into waters frequented by fish. This restriction applies to both the Crown and to private citizens and companies. The Clean Water Act (Section 17(1)) prohibits the deposit of a contaminant that would render water "harmful...to fish". Section 17(2) provides exceptions to Section 17(1).
6. Risk management options should be developed to stabilize or remove the sources of contamination, and to decontaminate, contain, divert or reduce off-site movement of contaminants in groundwaters and seepages, sands and gravels.

This report does not address contamination concerns after September 1991, or the progress of subsequent remedial activities at these sites.

1 PROJECT BACKGROUND

The material presented in the next two sections (1.1 Issue and 1.2 Current Status) has been taken from a document summarizing the situation and which was prepared by Alberta Environment (Anon, 1989).

1.1 Issue

In early 1982, Alberta Environment was made aware of groundwater contamination in the immediate vicinity of wastewater ponds operated by Celanese Canada Inc. In March 1982, the Director of Pollution Control Division issued a Water Quality Directive to Celanese Canada Inc to investigate the potential contamination of underground fresh water. In response to the Directive, Celanese Canada Inc., implemented a groundwater study and developed plans for closure of the wastewater ponds.

The investigation, conducted by Hardy Associates (1978) Ltd., included monitoring of seepage at points along the east bank of the North Saskatchewan River and sampling of an apparent discharge zone in the river bottom. The investigation identified organic contamination of both soil and groundwater north of the wastewater ponds. Although Total Organic Carbon (TOC) values exceeded 20,000 mg L^{-1} at some groundwater monitoring points, the exact nature of the organic contaminants could not be defined since many peaks on the GC/MS scan could not be identified. The extent of the underground contamination included the Clover Bar Sand and Gravel Ltd operation, but the contaminated water did not appear to surface in the gravel pits at that time.

Concerns were raised by Alberta Environment regarding both discharge of contaminated groundwater to the North Saskatchewan River and the potential impact on the Beverly Channel aquifer. Celanese Canada Inc. provided estimates on dilution rates for river discharge. They also presented technical information showing that aquifer contamination would only be localized since the aquifer was intercepted by the river just north of the investigation area.

The wastewater streams within the Celanese plant were redirected into a new system and the ponds were closed and capped during 1984-85.

A groundwater monitoring program was established in order to evaluate the natural rehabilitation of groundwater following removal of the contaminant source. This observation program was acceptable to Alberta Environment at that time.

Pollution Control Division, Alberta Environment, has been responding to complaints of contaminated groundwater at Clover Bar Sand and Gravel Ltd., since 1984. In 1986 Alberta Environment met with Celanese Canada Inc to develop a solution to contaminated groundwater seeping into new excavations at the gravel pits. Celanese has developed a system for collecting contaminated water in the gravel pit area and pumping it back to the plant and their deep disposal well. Total volumes of water pumped from the pits to the disposal well have been 8.5, 23.4 and 17.8 million imperial gallons for 1986, 1987, and 1988 respectively. In addition, Clover Bar Sand and Gravel has received a licence from Alberta Environment to discharge surface waters to the North Saskatchewan River with conditions specifying quality of the discharge.

In December, 1988, representatives from Alberta Environment and the Edmonton Board of Health met to review and discuss the situation and, in particular, the contamination of sand and gravel at the Clover Bar Sand and Gravel pits north of the Celanese plant. The Board of Health also expressed concerns regarding contaminants entering the drinking water cycle, i.e. downstream users, as well as other concerns.

1.2 Current Status

On February 2, 1989, representatives from Alberta Environment, Edmonton Board of Health and Celanese Canada Inc., met to review progress of groundwater reclamation and to discuss related impacts on the sand and gravel operation. Groundwater monitoring results showed that TOC levels in all wells have been declining since May, 1983, although TOC levels were still very high. The natural cleanup trend was considered to be good, but predictions could not be made regarding the time required to achieve total cleanup; that is, a return to background levels. Celanese will continue to intercept and pump contaminated groundwater back to their deep disposal well. Celanese will construct additional monitoring wells to assess the extent of the contaminant movement in the gravel pit and will report to Alberta Environment when this investigation has been completed. Clover Bar Sand and Gravel Ltd., is planning to move into more contaminated areas on their property. The Edmonton Board of Health does not have the resources to conduct an independent risk assessment of the situation and is relying on Alberta Environment for this.

1.3 Location

Celanese Canada Inc., occupies an industrial site in the City of Edmonton's east industrial area immediately south of the North Saskatchewan River. This industrial site is located in a groundwater recharge area. Several springs and seepages have been identified in the riverbank west of Celanese. The major aquifer is the permanent water table established in the sand and gravel unit. To the north of this industrial site, on a property known locally as Keltie Farm, Clover Bar Sand and Gravel Ltd is working these lenses as a commercial operation, with removal of sands and gravels off-site. Edmonton Power Generating Station lies between these two sites (Figure 1). Studies of the Celanese site were conducted by Hardy Associates in 1982 and 1986 at the request of Celanese Canada Inc. (Hardy Associates (1978) Ltd., 1982a; *Ibid*, 1982b; *Ibid* 1982c; *Ibid*, 1984).

1.4 Concerns

The toxicological assessment of the contaminants identified in the groundwater, gravel and sand associated with the industrial site occupied by Celanese Canada Inc., and Clover Bar Sand and Gravel Ltd., was developed at the request of Alberta Environment, Wastes and Chemicals Division (Taylor, 1990) for the Celanese Groundwater Contamination Study Group (CGCSG). The latter consists of staff from Alberta Environment, Edmonton Board of Health and the Alberta Environmental Centre.

Three concerns were identified by CGCSG:

a. movement of chemically contaminated groundwater into the North Saskatchewan River and into the gravel lenses;

b. removal of contaminated sand and gravel for commercial and residential purposes;

c. effects of exposure of people to the chemical contaminants.

This report is submitted to Alberta Environment and the CGCSG as part of their process of assessing the potential impacts of contaminated groundwaters, leachates, sands and gravels on off-site receptors, particularly people, as well as possible remediation procedures.

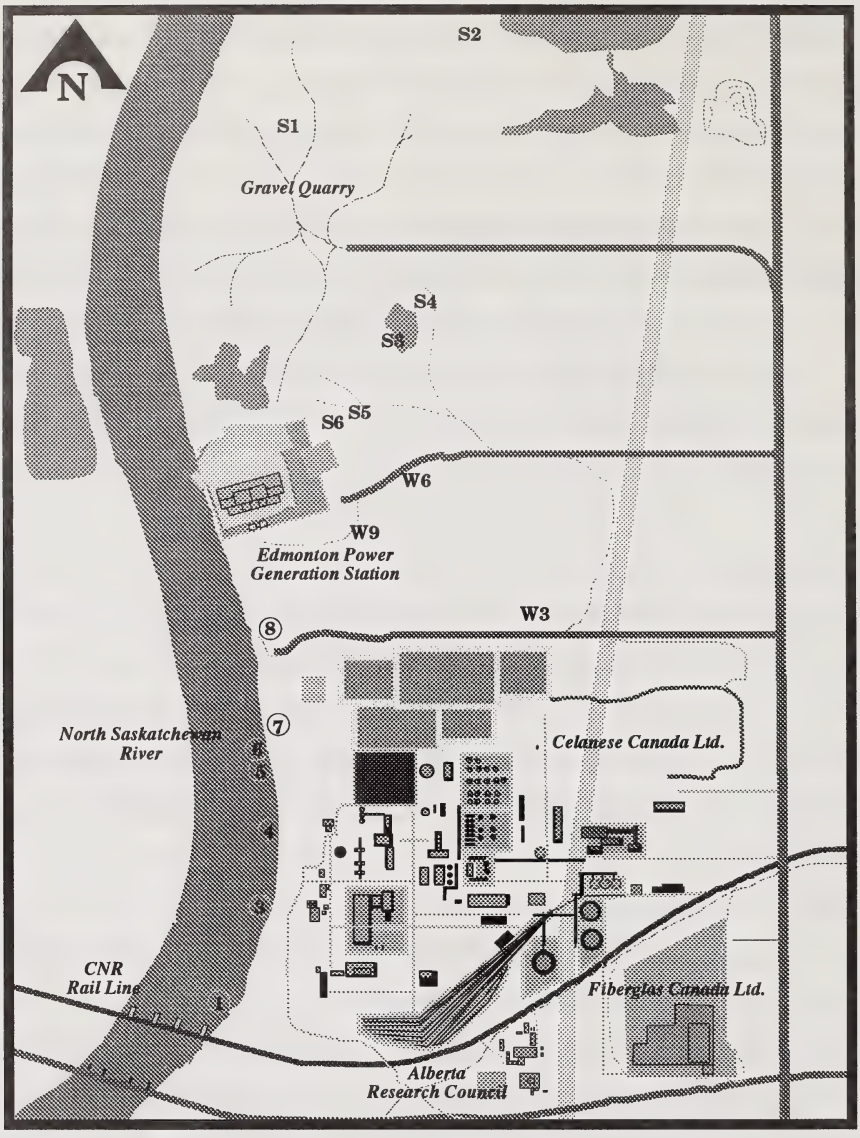

Figure 1 Industrial site east of the City of Edmonton.

Legend: Sampling Sites:

S1	Sand sample #1	S6	Sand sample #6
S2	Sand sample #2	W3	Well #3
S3	Sand sample #3	W6	Well #6
S4	Sand sample #4	W9	Well #9
S5	Sand sample #5	#7	Seepage site #7
	1 through 8	Observed sites during tour of river bank	

1.5 Purpose

The primary purpose of this assessment is to identify and assess, either quantitatively or qualitatively, the potential health risks that might arise following direct or indirect exposure to the contaminated groundwaters, leachates, sands and gravels, either on or off the site. Thesecondary purposes are to identify information gaps pertinent to the above concerns, and to indicate possible actions to reduce the toxicological impacts.

It is important to note that this assessment does not:

a. assess the economic or mechanical impacts of utilizing chemically contaminated sands and gravels, including restrictions as to their usage;

b. assess the ecological effects of the movement of chemically contaminated groundwaters into the North Saskatchewan River;

c. make comparisons to other sites or industries;

d. develop plans for remedial actions for contaminated groundwaters, leachates, sands or gravels, nor propose courses of action to be taken by either Alberta Environment or the Edmonton Board of Health.

1.6 Objectives

The four objectives of this risk assessment are:

a. **to identify** the chemical contaminants in groundwater, leachate, sand and gravel;

b. **to establish** a short list of indicator chemicals to enable qualitative and quantitative assessment of the potential for exposure of people and animals;

c. **to identify** possible public health effects associated with such exposures;

d. **to catalogue** gaps in information concerning the contaminated groundwaters, sands and gravels, their biological effects, and the probability of such effects occurring.

2 TOXICOLOGICAL BACKGROUND

The development of formal chemical risk assessments of major industrial sites in Alberta is not common. It is likely that such undertakings will become more frequent in the future. For this reason, the risk assessment guidelines outlined for Superfund were used (U.S. Environmental Protection Agency, 1987d; *Ibid*, 1989b; *Ibid*, 1989c).

The degree of sophistication of the process may vary from cursory to intense. The latter is detailed, time-consuming, costly, and requires a multi-disciplinary approach necessitating the cooperation of many agencies. This report includes information from industry, private consultants, federal and provincial departments, and a municipal board of health.

2.1 Biological Effects

This report addresses the potential health effects of exposure to the contaminated groundwater, leachate, sand and gravel. Such health effects can be categorized as either biological or psychological. These categories may be further divided into life-threatening and non life-threatening. Further, both the categories can be sub-divided into reversible or irreversible.

Some examples:

* malignant cancer is an irreversible, life-threatening, biological change;
* a cough is a reversible, non-life-threatening, biological change;
* depression may be a life-threatening psychological change;
* a noxious odour has a non-life-threatening psychological impact.
* food poisoning may be debilitating, reversible, non-life-threatening, biological change in most but not all people.

The last example indicates there are variations in biological response. Some individuals within the population may respond differently to the same chemical dose; some will be hypersusceptible, others hyposusceptible. In some people hypersusceptibility or hypersensitivity may develop as a result of either a single exposure or repeated exposures.

This report deals with the toxicity of chemicals. Within this context, toxicity is defined as the inherent capacity of a substance, through its chemical or physical properties, to produce injury to a living organism.

The goal is to determine the relationship between the dose of the chemical and the potential development of adverse effects (Turturro & Hart, 1987).

The dose-response relationship states that there is an increasing response with increasing dose, as depicted by the S-shaped curve in Figure 2. Individuals in a population may differ in their response to an increasing dose, as illustrated by the graph in Figure 3, which depicts the typical cumulative frequency response curve for a normal population.

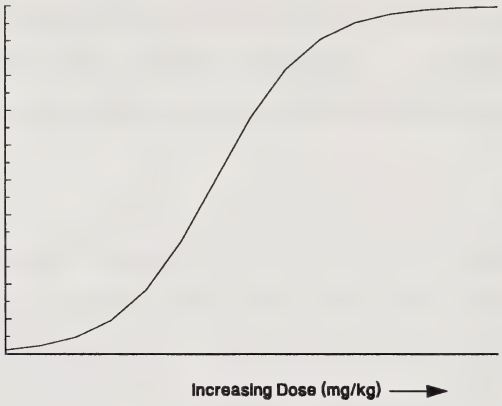

Figure 2 Dose-response curve for a normal population.

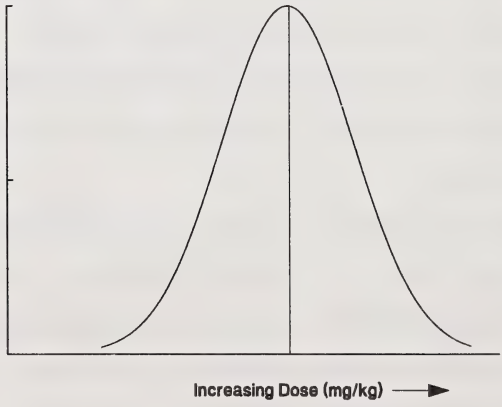

Figure 3 Distribution of a normal population.

Only a few individuals will respond at very low doses. Usually the number of these sensitive (hyper-susceptible) individuals is less than 5 per cent of the total exposed population.

Conversely, a very few individuals will respond only at very high doses, again the number of resistant (hypo-susceptible) individuals is about 5 per cent of the population.

2.2 Overview

Chemical risk assessment is the evaluation of the risk entailed in human or animal exposure to hazardous chemicals. This is accomplished through the use of published epidemiological and experimental information to derive a quantitative value for the estimate of probability of harm occurring to exposed populations. The process neither identifies a guaranteed safe concentration of a substance nor safeguards against harm; and the process has both logical and intuitive components.

Risk has two components to consider:

* **Hazard** is the potential for injury inherent in the physico-chemical properties of a specific compound or mixture of compounds;
* **Probability** is the potential realization of unwanted consequences of an event (Rowe, 1986). That is, risk is the probability of injury, disease or death under specific circumstances (U.S. Environmental Protection Agency, 1987a).

An early model of risk assessment and risk management processes (Kates 1978; Whyte and Burton, 1980) has been refined to portray the process in greater detail (Lave, 1982; Interdepartmental Working Group on Risk-Benefit Analysis, 1984) for assessing risk (Rowe, 1977; Whyte and Burton, 1980; Ricci *et al*, 1984) and determining acceptability of risk (Fischoff *et al*, 1978; Schwing and Albers, 1980).

Frequently, social and political dimensions (risk management) are added to the scientific dimensions of risk assessment (Sasseville and Crowley, 1988).

3 HAZARD IDENTIFICATION

Question to be asked: What chemicals are present?

The quantities and use of chemicals brought onto this industrial site by Celanese Canada Inc., are summarized in Table 1 (adapted from Hardy Associates [1978] Ltd., 1982c). It should be noted that additional sources of industrial chemicals might include Uniroyal Chemical Ltd., Monsanto Canada Inc., Rheem Canada Inc., and others in the area. Identification of possible sources is important in assessing the extent of potential contamination. Of the 96 chemicals and industrial compounds used at Celanese Canada Inc. during the period 1953-1980 (Table 1), 57 (59%) have applicable Occupational Exposure Levels (ACGIH, 1990).

Table 1 Quantities and use of chemicals brought onto Celanese site 1953-1980.

CHEMICAL	A[1]	USE[2]	CHEMICAL	A[1]	USE[2]
Absorption oil	3	R	*Lithium bromide	1	R
*[3] Acetaldehyde	5	I, R	Lubricating oils & greases	2	R
Acetaldol	3	BP	*Magnesium oxide	2	R
*Acetic acid	5	P, R	Magnesium acetate	4	I
*Acetic anhydride	5	P, R	Magnesium sulphate	4	BP
*Acetone	5	R, P	Manganese acetate	2	R
*Acetonitrile	4	P	Mercaptans	1	R
*Acrolein	4	BP	*Mesityl oxide	4	I
*Acrylic acid	5	I, P	Metalose™	1	R
Alum	3	R	*Methanol	5	I,R,P
Aluminum chloride	2	R	*Methyl ethyl ketone	5	R,P
Amyl alcohols	4	R, P	*Methyl formate	3	BP
Amyl acetates	4	P	Methyl hydroquinone	1	R
*Ammonia	2	R	Methyl acetate	5	I
Antifoamers	1	R	*Methylene chloride	4	R
Benzene sulphonic acid	3	R	Methylal	3	BP
*Benzene	4	R	*Methyl isobutyl ketone	4	R,P
Butanols	4	R, P	Mineral oil	3	R
*Butyl acetates	4	R, P	Monoethanolamine	2	R
Butylaldehyde	4	I	Monopentaerythritol	2	R
Butyric acid	4	BP	*n-Butane	5	R
Calcium hypochlorite	1	R	*n-Butyl acrylate	4	P
Calcium acetate	2	I	Natural gas	5	R
Calcium chloride	2	R, P	Nimox	2	R
*Calcium sulphate	3	BP	*Nitric acid	1	C
Calgon CL45™	1	R	Nitrilotriacetic acid	1	R
Cellulose acetate	5	P	*Oxalic acid	2	R, BP
*Cellulose pulp	5	P	*Pentaerythritol	4	P

Table 1 (con't.)

CHEMICAL	A[1]	USE[2]	CHEMICAL	A[1]	USE[2]
Cellulose triacetate	4	P	*Pentane	3	R
Cellulose acetate flake	5	P	*Phenothiazine	1	R
*Chlorine	3	R	*Phosphoric acid		R
Chromium corrosion products	2	BP	*Potassium hydroxide	2	R
Cigarette filter tow	5	P	Potassium amyl xanthate	5	P
Cobalt nitrate	1	R	Potassium permanganate	1	R
Cobalt acetate	1	R	Potassium carbonate	2	I
Chromic acid	2	R	Potassium acetate	2	BP,R
Copper acetate	1	R	Precious metal catalysts	1	R
*Crotonaldehyde	4	I	*Propane	5	R
Cyclohexane	2	R	n-Propanol	4	R,P
Dearborn 3254	2	R	Propionaldehyde	4	I,P
Diacetone alcohol	4	I	*Propionic acid	4	BP
Diammonium phosphate	4	R	Propyl acetate	4	P
Diesel fuel	3	R	*Propylene glycol	3	P
*Diethanolamine	2	R	*Propylene oxide	3	I
Dimethyl acetal	3	BP	Rany nickel	2	R
*Dipropylene glycol	3	P	*Resorcinol	1	R
Disodium phosphate	3	R	Sanfax™	2	R
Emulsifiers	2	R	Separan™	1	R
Ethanol	4	BP, P	Silver	2	R
Ethyl hexyl acrylate	4	P	Sodium carbonate	3	R,BP
*Ethyl acrylate	4	P	Sodium isobutyl xanthate	5	P
*Ethyl acetate	4	I, P	Sodium chloride	4	R
Ethyl hexanol	4	R	Sodium acetate	4	BP
*Ethylene glycol	2	R	Sodium formate	5	BP
*Ethylene	5	R	Sodium sulphite	1	R
*Ethylene glycol diacetate	4	BP	Sodium sulphate	1	R
Filming amines	1	R	*Sodium hydroxide	5	R
Finish oils	3	R	Succinic acid	3	BP
*Formaldehyde	5	R,P	*Sulphuric acid	4	R
*Formic acid	4	BP	Tertiary butanols	3	R
Freons	2	R	Tide™	2	R
Gamma butyrolactone	3	R	Titanium dioxide	4	R
Gasoline	3	R	TMO™	3	P
Glycol laurate	1	R	Toluene sulphonic acid	3	R
*n-Hexane	2	R	*Trichloroethane	2	R
*Hexyl acetates	4	P	Tripropylene glycol	3	P
Higher alcohols	3	P	*Vinyl acetate		R
*Hydrazine	1	R	*Xylene	3	R
*Hydrochloric acid	2	R	*Zinc chromate	2	R
Iron oxides	2	BP	Zinc	1	R
Isopropanol	4	R,P	*Zinc oxide	2	R
*Isopropyl acetate	4	P			

[1]Amount used annually: 1=few drums/pails; 2=<50 tons; 3=50-500 tons; 4=500-5000 tons; 5=>5,000 tons.
[2]I = Intermediate; R = Raw Material; BP = ByProduct; P = Product; C = Cleaner
[3]* = Occupational Exposure Limits published for these chemicals

3.1 Chemicals Detected in Groundwater, Sand and Gravel Samples

Walking the riverbank and viewing from a boat in the area of known seepage sites near Celanese Canada Inc., resulted in the observations listed in Table 2. The sampling locations are identified in Figure 1.

Table 2 Observations recorded during tour of river bank at site.

Site	Observation
1	100 yds North of the railway bridge, a small flowing stream was evident (no apparent odour or colour).
2	10 yds South of Celanese's inlet water pumphouse return backwash outfall, another flowing stream was observed. Vegetation was thick and lush. The stream has a strong sulphurous odour. Following the stream toward the pumphouse area, a white-grey residue on the soil was observed.
3	Celanese's intake water backwash outfall.
4	Celanese's South Flume outfall.
5	Celanese's North Flume outfall.
6	20 yds North of North Flume - presumed location of seepage site #6 (underwater) marked by a stump. No seepage evident during tour.
7	10 yds North of seepage site #6. Strong sweet-like odour and reddish brown colour. Seepage recovery facilities on bank.
8	250 yds North of site #7, another visible flow was observed. Strong sweet-like odour. Following flow up the riverbank, the emanating point was about 100 yds up the bank. The small ravine was dammed at one location and 1.25 inch PVC hose and electrical cables were lying on the ground. The hose ran back to the large recovery culvert at seepage site #7.

Grab samples of seepage fluids, sand, and groundwater were taken by staff of Alberta Environment. These samples were analyzed by four laboratories: Alberta Environmental Centre (AEC), Core Laboratories, Enviro-Test Laboratories and NorWest Laboratories. The analytical results are summarized in Tables 4 through 17.

Site descriptions are listed in Table 3 and concentrations of chemicals detected in sand, gravel and water at sites S1 through S6 are summarized in Tables 4 through 9. Results of

organic chemical analyses of samples from the SE Seepage Pond and gravel pit are summarized in Table 10; from groundwaters at Wells #3, #6 and #9 in Table 11; from Seepage Site #7 in Table 12; for inorganic chemical analyses of samples from Wells #3, #6 and #9, Seepage Site #7, and gravel pit in Tables 13 and 14; for organic mixtures from Seepage Site #7, processed sand, and sand and water in Table 15; and Total Organic Carbon in Table 16. The results of bioassays are summarized in Table 17. It should be noted that the values reported by the Alberta Environmental centre have been adjusted for dilutions of the original samples for analytical purposes. Thus the values listed represent leachable concentrations from the original samples.

Table 3 Description of sampling sites at Clover Bar Sand and Gravel Ltd.

Site S1	Sample taken of freshly processed sand as it came off the conveyor belt. This site was in the centre of the processing plant site.
Site S2	In the NE quadrant of NW 20 where current excavating is taking place. The samples was removed from the shovel scoop material taken from 1 metre above the water table.
Site S3	Located in the SE of SW 20 in an area where *in situ* sand was being removed by truck. Taken 12 inches below standing water.
Site S4	Located 25 metres NE of S3 in a previously excavated pit. Taken from cleaned face at the nose of the pit wall approximately 2 metres above the water table.
Sites S5 and S6	These sites located along south property boundary. S5 where obvious seepage was occurring as indicated by dark staining; S6 taken from sand layer above S5.

Table 4 Chemicals identified in freshly processed sand at Site S1.

Chemical	Concentration (ppm)
Aliphatic & Acyclic Hydrocarbons	3.5
Benzo(a)anthracene	5
Benzthiazole	0.08
2,4-Dichlorophenoxyacetic acid	0.07
Heterocyclic aromatics	0.06
Naphthalene	5
Phenanthrene	5
Phenol	310
Phenolics	0.21
Polycyclic aromatics	0.25
Substituted benzenes	0.21

Table 5 Chemicals identified in scoop material at Site S2.

Chemical	Concentration (ppm)
Aliphatic & Acyclic Hydrocarbons	125
Heterocyclic aromatics	50
Phenol	3
Phenolics	1
Polycyclic aromatics	25
Substituted benzenes	4
Unresolved aliphatic/aromatics	750

Table 6 Chemicals identified in sand below water at Site S3.

Chemical	Concentration (ppm)
Aliphatic & Acyclic Hydrocarbons	1500
Aromatic heterocyclics	650
Benzthiazole	100
Bis(2-ethylhexyl)phthalate	5
2,4-Dichlorophenoxyacetic acid	0.16
Fluoranthene	5
Naphthalene	5
Phenanthrene	5
Phenol	300
Phenolics	40
Picloram	0.02
Polycyclic aromatics	200
Substituted benzenes	100

Table 7 Chemicals identified in sand from cleaned face at Site S4.

Chemical	Concentration (ppm)
Aliphatic & Acyclic Hydrocarbons	60
Heterocyclic aromatics	40
Phenolics	1
Polycyclic aromatics	15
Substituted benzenes	10
Unresolved aliphatic/aromatics	300

Table 8 Chemicals identified in sand from seepage area at Site S5.

Chemical	Concentration (ppm)
Acetaldehyde	1.96
Acetone	12.6
Aliphatic & Acyclic Hydrocarbons	3000
Benzene	24
Benzthiazole	60
Bibutylphthalate	0.005
Dimethoxymethane	17.8
Heterocyclic aromatics	350
Isopropanol	0.66
3-Methyl-2-butanol	0.4
Methyl butyl ketone	1
Methyl ethyl ketone	0.74
Methyl isobutyl ketone	5.4
2-Methyl-2-propanol	0.4
Naphthalene	0.005
Phenanthrene	0.005
Phenol	0.33
Phenolics	40
Picloram	0.05
Polycyclic aromatics	90
Substituted benzenes	130
Tetrahydrofuran	0.6

Table 9 Chemicals identified in stained sand (above Site S5) at Site S6.

Chemical	Concentration (ppm)
Acetone	0.6
Aliphatic ethers	15
Aliphatic & Acyclic Hydrocarbons	100
Benzene	0.001
Dimethoxymethane	0.6
Heterocyclic aromatics	40
Methyl ethyl ketone	0.8
Methyl isobutyl ketone	0.2
Methyl isopropyl ketone	0.04
Methyl propyl ketone	0.05
Phenol	2
Phenolics	1
Polycyclic aromatics	2
Substituted benzenes	25
Unresolved aliphatic/aromatics	600

Table 10 Chemicals identified in fluids from SE seepage area and gravel pit.

Chemical	Concentration (ppm) at Site		
	Seepage area	Gravel Pit	
Acetone			.5[b]
Acetic acid	NR[1]	NR	74[b]
Benzene	0.088[c]	0.049[c]	0.036[b]
Butanol			1.3[b]
Butyric acid		NR	55[b]
Ethylbenzene			0.001[b]
Isopropanol			1.5[b]
Propionic acid	NR	NR	140[b]
Total Dissolved Solids			6300[d]
Total Organic Carbon	2100[d]	5280[d]	

[1]NR = Not Reported
[b] = Core Laboratories
[2c] = Enviro-Test Laboratories
[d] = NorWest Laboratories

Table 11 Chemicals identified in waters from Wells #3, #6 and #9.

Chemical	Concentration (ppm)			
	Well 3	Well 6	Well 9	
Acetic acid	3600	450	120	
Benzene	0.003	0.001	0.1	0.14
n-Butanol	0.9	0.9	1.3	
Butyric acid	92	230	170	
Ethylbenzene	0.001	0.001	0.024	
Isobutyric acid	240	9	9	
Isopropanol	0.9	0.9	1.5	
Methyl ethyl ketone	0.9	0.9	5.2	
Propionic acid	160	1100	230	
Toluene	0.002	0.004	0.037	
Xylenes	0.001	0.001	0.024	
Total Dissolved Solids	9650	7.16	11300	
Total Organic Carbon	15100	8910	12100	

Table 12 Organic chemicals identified at Seepage Site #7.

Chemical	Concentration (ppm)	
Acetaldehyde	0.4	
Acetic acid		37
Acetone	1.7	3
Benzene	0.037	0.13
n-Butanol		<1
Butyric acid		54
Chloroform	0.001	
Dimethoxymethane	2.4	
Ethyl acetate	10.5	
Ethylbenzene		0.005
Ethyl propionate	0.35	
Isobutyric acid		<10
Isopropanol		<1
Methyl acetate	1.3	
Methyl butanoate	0.3	
Methyl ethyl ketone	30	17
Methyl isobutyl ketone	0.8	
Propionic acid		96
Toluene		0.018
Total Dissolved Solids	1700	
Xylenes		0.004

Table 13 Inorganic elemental analyses of water samples from various sites.

Parameter	Well #3[1]	Well #6[1]	Well #9[1]	Seep #7[1]	Seep #7[2]	Gravel Pit[1]
Ca	2380	820	1120	322	248	242
Mg	990	632	238	135	108	115
K	15.6	11.7	16	5.9	5	8.6
Na	301.3	2116	4462	407	330	2829
NH_4-N	0.5	0.3	0.4	0.17		1
$N0_3$-N	<0.15	<0.15	<0.15	<0.15		<0.15
(NO_2+NO_3)-N					0.03	
NO_2-N					0.006	
Cl	401	152	288	131	107.5	136
SO_4	276	53	43	24	17	77
CO_3-HCO_3	5227	6829	10356	1362		5871
Bicarbonate					1158	
Fe	378	331	396	54.4	69.03	103
Mn	41	4.1	14.2	9.7	5.92	4.13
Cu	0.03	0.01	0.01	<0.01	0.006	<0.01
Zn	0.28	0.33	0.45	0.29	1.065	0.145
Pb	<0.02	<0.02	<0.02	<0.02	0.072	<0.02
As					0.086	
Be					<0.001	
Se					0.0005	
Hg					<0.0001	
Ba					1.105	
Cd					0.009	
Mo					0.011	
Ni					0.062	
Co					0.045	
Cr					0.015	
Va					0.023	
Al					0.023	

Table 14 Inorganic analyses of water samples from various sites.

Parameter[1]	Units	Well #3[2]	Well #6[2]	Well #9[2]	Seep #7[2]	Seep #7[3]	Gravel Pit[2]
pH		6.43	6.6	6.46	6.88	6.97	7.23
EC	mS cm^{-1}	18.6	10.95	16.7	3.45		9.86
Conductivity	uS cm^{-1}					2820	
SAR	ppm	13.1	13.4	31.5	4.8		37.4
TH	ppm	10000	4690	3790	1360	1063	1080
TDS	ppm	9650	7160	11300	1700		6300
TDS (Calculated)	ppm					1385	
TDS (By Difference)	ppm					3234	
COD	ppm	43600	28700	37900	8760	6483	16200
T-Alkalinity	ppm	4200	5600	8500	1120	950	4810
BOD	ppm					3308	
Total Solids	ppm					3452	
T-Susp. Solids	ppm					218	
Odour	TON					1000	
TKN	ppm					2	
DOC	ppm					2200	
DIC	ppm					126	
Carbon Part	ppm					14.3	
Nitrogen Part	ppm					0.44	
Cations						35.73	
Anions						22.39	
Balance						1.6	

Table 15 Chemical mixtures identified at various sites.

Chemical	Site	Conc (ppm)	Site	Conc (ppm)	Site	Conc (ppm)
Substituted benzenes	Proc Sand	0.21	KF seep	0.13	Sand, water	0.1
Benzthiazole	Proc Sand	0.08	KF seep	0.06	Sand, water	0.1
Polycyclic aromatics	Proc Sand	0.25	KF seep	0.09	Sand, water	0.2
Phenolics	Proc Sand	0.21	KF seep	0.04	Sand, water	0.04
Aliphatic and aromatic hydrocarbons	Proc Sand	3.5	KF seep	3	Sand, water	1.5
Heterocyclic aromatics	Proc Sand	0.06	KF seep	0.35	Sand, water	0.65
Ethers	Seepage #7	2.0				
Ketones	Seepage #7	1.1				
Alcohols	Seepage #7	1.6				
Aldehydes	Seepage #7	1.0				
Acids	Seepage #7	5.0				

Table 16 Values for Total Organic Carbon in samples taken from five sites.

Sampling Location	Total Organic Carbon (ppm)
Well #3	15 100
Well #6	8 910
Well #9	12 100
Gr Gravel Pit	5 280
SE Seepage Pond	2 100

Table 17 Results of bioassays conducted at the Alberta Environmental Centre..

Species	Site	48 h LC_{50}	Site	96 h LC_{50}	48 h LC_{50}
Oncorhynchus mykiss	Seepage #7	2.24 %	Gravel Pit Effluent	64.7 %	NR[1]
Pimephales promelas	Seepage #7	2.24 %	Gravel Pit Effluent	47.9 %	NR
Daphnia magna	Seepage #7	<3 %	Gravel Pit Effluent	NR	39.4%

[a] = Core Laboratories [b] = Alberta Environmental Centre [1] = Not Reported

3.2 Analytical Profiles

Gas chromatography/mass spectroscopy (GC/MS) analysis was conducted on samples taken from various locations on the property known as Keltie Farm (Clover Bar Sand Gravel Ltd).

The results of multiple ion GC/MS analysis of samples of processed sand (S1), sand and gravel samples from above the water level (S2), sand from below water level (S3), sand (S4), sand from a seepage area (S5) and sand and gravel seepage area (S6) are presented in Tables 4 and 5.

The results of single ion GC/MS analysis of samples of processed sand (S1), sand and gravel samples from above the water level (S2), sand from below water level (S3), sand (S4), sand from a seepage area (S5) and sand and gravel seepage area (S6) are presented in Tables 6 and 7.

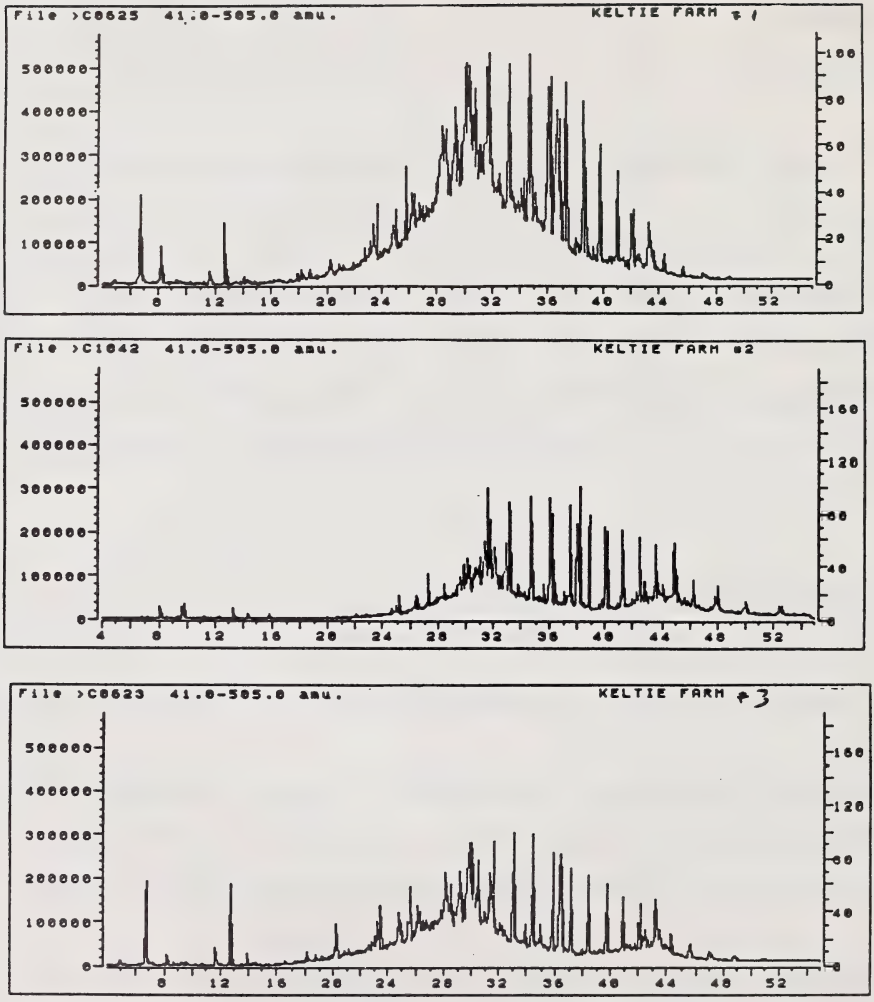

Figure 4 Multiple ion GC/MS analyses of samples of processed sand (S1), sand and gravel samples from above the water level (S2) and sand from below water level (S3).

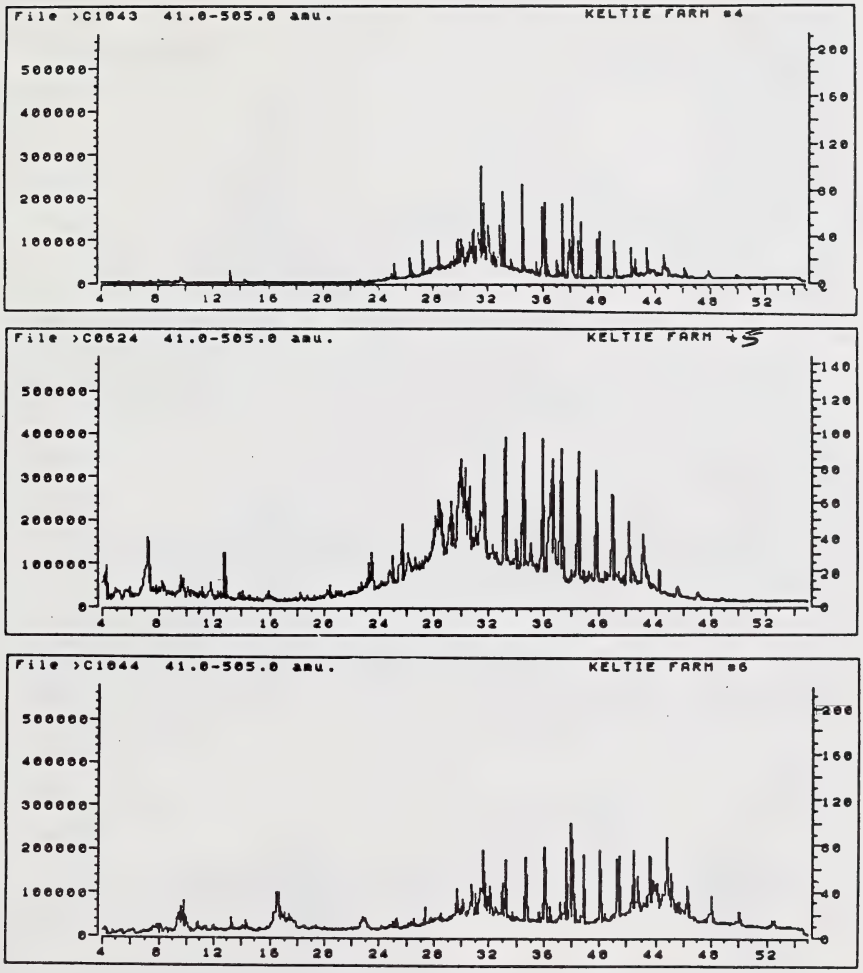

Figure 5 Multiple ion GC/MS analyses of samples of sand (S4), sand from a seepage area (S5) and sand and gravel seepage area (S6).

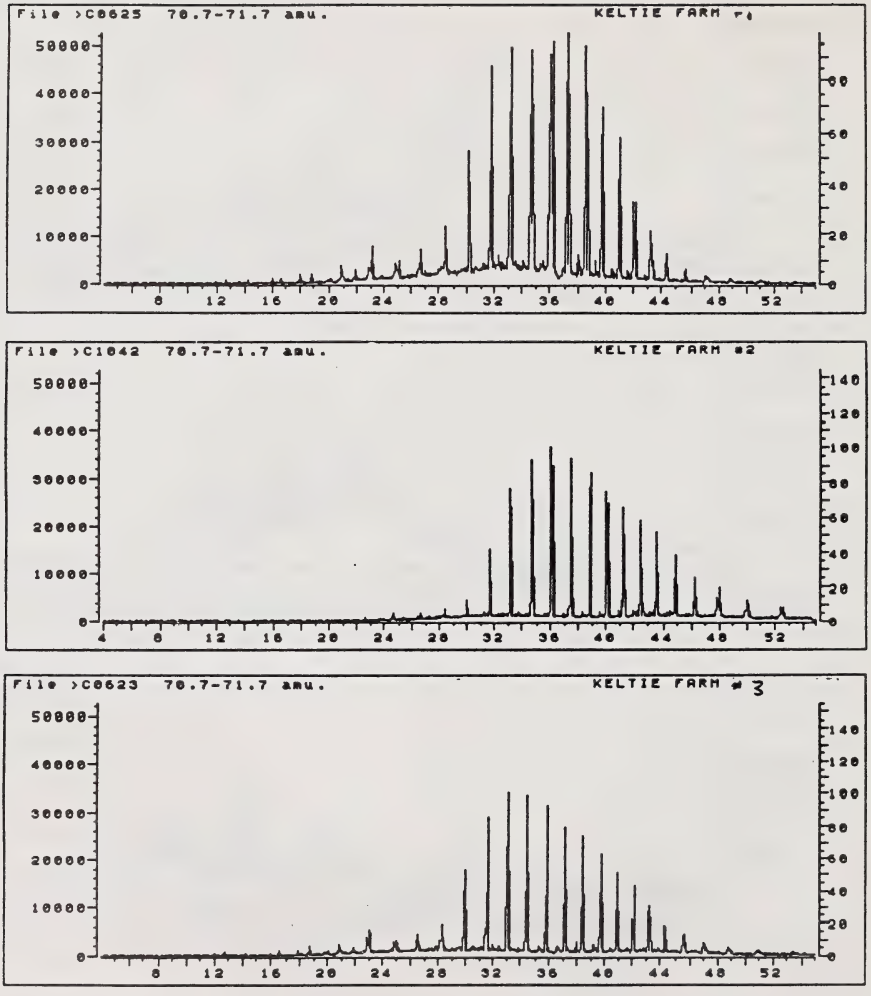

Figure 6 Single ion GC/MS analyses of samples of processed sand (S1), sand and gravel samples from above the water level (S2) and sand from below water level (S3).

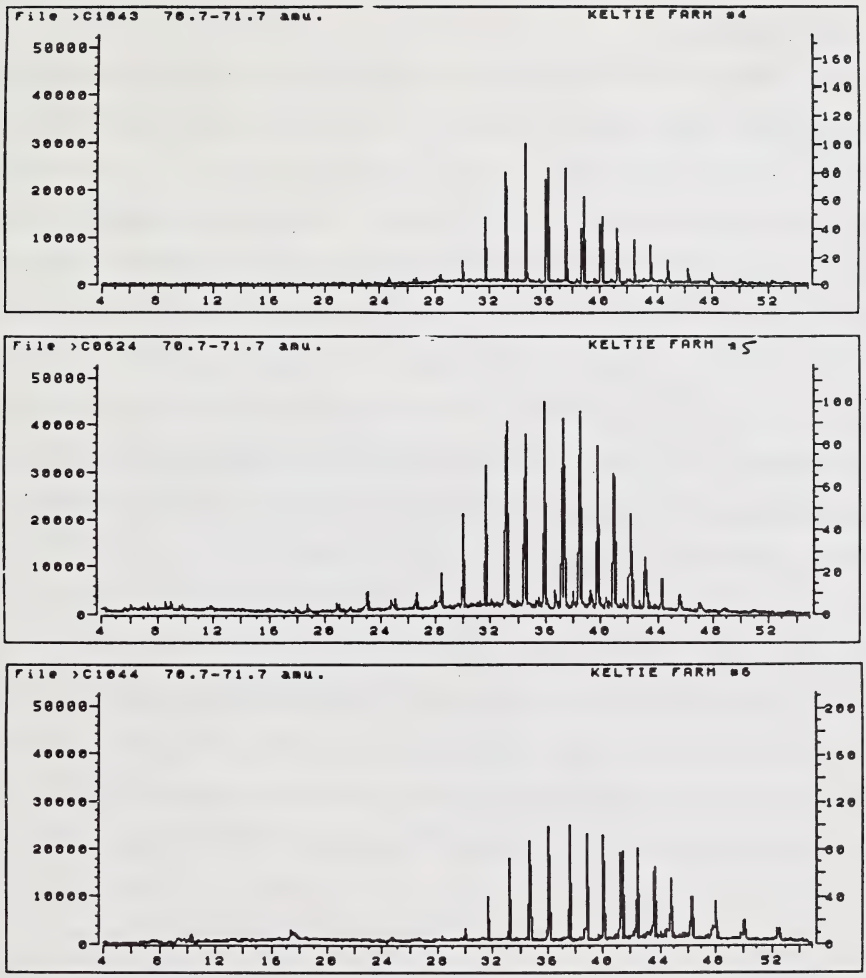

Figure 7 Single ion GC/MS analyses of samples of sand (S4), sand from a seepage area (S5) and sand and gravel seepage area (S6).

These profiles indicate a shift in the apex of peak envelopes to larger retention times indicating a higher relative loss of the more volatile compounds. The patterns are consistent with contamination from the same source.

3.3 Data Validation

Data validation is very important in health risk assessments. The formulas and calculations used to determine health risks have become quite complex (Hellmann and Cheatham, 1989). The reliability of the data generated by laboratory analysis of environmental and health samples, epidemiological studies or medical records, will affect the calculations. In the U.S.A. there are specific guidelines to be used for evaluating laboratory analyses and associated data from members of the Contract Laboratory Program (U.S. Environmental Protection Agency, 1985a; *Ibid*, 1985b). In addition, this agency has issued guidelines for determining the appropriate quality of data required for a specific decision based on that data (U.S. Environmental Protection Agency, 1987b; *Ibid*, 1987c). No attempt was made during this assessment to verify the quality assurance and control processes at the laboratories carrying out the analytical chemical or bioassay procedures.

3.4 Electron Microscopy of Sand Particles

Sand samples from Clover Bar Sand and Gravel Ltd. were examined by scanning electron microscopy. Material was observed adhering to the surface. The nature of this extraneous material could not be determined, but might be organic material, or soil or clay particles. Such materials were not observed on the surface of sand particles from a control site.

4 ENVIRONMENTAL FATE MODELLING

Two separate but related water quality models were available for modelling the environmental fate of chemicals released into the North Saskatchewan River:

a. Stochastic River Quality Model, V2.0 (HydroQual Consultants Inc., 1989a; Gore and Storrie Ltd., 1989a);

b. Water Quality Event Model (MULTI) (HydroQual Consultants Inc., 1989b; Gore and Storrie Ltd., 1989b).

4.1 Stochastic River Quality Model

This model consists of three separate components: DOSTOC (simulating dissolved oxygen), NUSTOC (which simulates nutrients) and UNSTOC (to simulate other unspecified substances.

The UNSTOC model was used to simulate the effects of groundwater contaminant flow from the Celanese industrial site on the North Saskatchewan River. The input for this model consists of a physical definition (reach, length, location of point sources and tributaries, etc), hydraulic characteristics (velocity, depth and width coefficients), river and inflow quantity and quality, process coefficients (decay, sedimentation and volatilization). Maximum concentrations of detected chemicals were used as contaminant concentration inputs. Contaminant concentrations in the river and other point sources were set to zero.

The decay, sedimentation, volatilization and diffuse runoff coefficients were set to zero to simulate a "worst case scenario". Discharge of the North Saskatchewan River was chosen to represent the range of discharge in the river. Only discharge records at Edmonton since 1972 were taken into account, the year that the Bighorn Dam was completed. Records at Edmonton indicate a lowest recorded monthly flow of 76 $m^3 s^{-1}$, a mean monthly low flow of 113 $m^3 s^{-1}$ and a mean monthly high flow of 339 $m^3 s^{-1}$. These flows were used in the UNSTOC model to represent the "worst case" scenario and the probably range of river discharge.

4.2 Water Quality Event Model

This model simulates concentrations of a contaminant at a certain location after a spill. Input to the model consists of a characterization of the spill (duration, with discharge and concentration profiles), river background concentrations and discharge, coefficients for longitudinal and lateral mixing, and hydraulic characteristics.

4.3 Modelling Results

Modelling is useful in the estimation of downstream concentrations of chemicals discharged into the North Saskatchewan River. It is very unlikely that anyone would drink the undiluted groundwater. However, waters are taken from the North Saskatchewan River downstream from the Celanese site by a number of licences for a variety of uses (Table 18).

Table 18 Downstream licensed users of water from North Saskatchewan River.

Legal Land Description	Applicant Name	Statutory Purpose	Max. Ann. Div. m^3
SW14-054-23-W4	Visser Farms Ltd	Irrigation	200
SW14-054-23-W4	Visser, Doug	Irrigation	13
SW14-054-23-W4	Riverbend Gardens*	Irrigation	39
SW14-054-23-W4	Riverbend Gardens*	Irrigation	47
NW06-053-23-W4	Prins, Simon	Irrigation	77
NW06-053-23-W4	Imperial Oil Enterprises Ltd	Industrial	1
NE07-053-23-W4	Alta Recreation & Parks	Other Water Use	28
NE07-053-23-W4	Petro-Canada Products,	Industrial	2866
NE07-053-23-W4	Petro-Canada Products,	Industrial	1827
NW17-053-23-W4	Celanese Canada Inc	Industrial	8500
NW17-053-23-W4	Uniroyal Chemical, Div of Uniroyal	Industrial	4
SW20-053-23-W4	City of Edmonton	Power Generation	190000
SW20-053-23-W4	City of Edmonton	Power Generation	175000
SE21-053-23-W4	Imperial Oil Enterprises Ltd	Industrial	2905
SE21-053-23-W4	Imperial Oil Ltd	Industrial	4595
NW26-053-23-W4	Wallish Greenhouses Ltd	Irrigation	6
NW28-053-23-W4	Raven Crest Holdings Ltd	Parks	150
SE28-053-23-W4	Stewart, Duncan R	Irrigation	100
SE30-053-23-W4	Gem Sod Farm Ltd	Irrigation	300
RL03-055-22-W4	Dow Chemical Canada	Industrial	17425
RL03-055-22-W4	Sherritt Gordon Mines Ltd	Industrial	2940
RL03-055-22-W4	Union Carbide Canada Ltd	Industrial	565
RL03-055-22-W4	Chevron Canada Resources Ltd	Industrial	807
RL05-055-22-W4	Sherritt Gordon Mines Ltd	Industrial	1500
RL05-055-22-W4	Marsulex Inc	Industrial	200
RL05-055-22-W4	Marsulex Inc	Industrial	440
RL08-055-22-W4	Gem Sod Farms Ltd	Other Water Use	197
RL08-055-220W4	Gem Sod Farms Ltd	Other Water Use	174
RL08-055-22-W4	Gem Sod Farms Ltd	Other Water Use	518
NW10-055-22-W4	B.F.Goodrich Canada Inc	Industrial	810
SW23-055-22-W4	Amoco Canada Petroleum Co Ltd	Industrial	40

Table 18 (con't.)

Legal Land Description	Applicant Name	Statutory Purpose	Max. Ann. Div. m^3
SW23-055-22-W4	Amoco Canada Petroleum Co Ltd	Industrial	3100
SE26-055-22-W4	Manderley Turf Farms Ltd	Irrigation	329
NW06-056-21-W4	Procor Ltd	Industrial	100
NW06-056-21-W4	Procor Ltd	Industrial	709
SE06-056-21-W4	Shell Canada Resources Ltd	Industrial	6680
NE06-056-21-W4	Northwestern Utilities Ltd	Industrial	3000
NE17-056-21-W4	Esso Chemical Alta Ltd	Industrial	6450
NE17-056-21-W4	Esso Chemical Alta Ltd	Industrial	6230
SW36-056-21-W4	Imperial Oil Ltd	Industrial	1500
SE06-057-20-W4	Campbell, Duncan	Industrial	585
SW09-057-21-W4	Sil Silica Ltd	Industrial	535
SW09-057-21-W4	Sil Silica Ltd	Industrial	1400
SW06-059-15-W4	Alta Government Services	Irrigation	231
SW06-059-15-W4	Alta Government Services	Irrigation	369
SE04-058-15-W4	Huchulak & Minaila, Eugene & LA	Feedlots	15
SE34-055-12-W4	Western Truck Body Manufacture	Industrial	315
SW35-055-12-W4	St Jean, Marcel	Irrigation	3
SW06-056-07-W4	Alta E & N Resources	Lake Stabilization	1800
SW25-056-07-W4	McCuaig, Gordon & Teresa	Irrigation	35
NE21-056-06-W4	Norwest Oil & Gas Corp	Injection	2420
BE21-056-06-W4	Amoco Canada Petroleum Co Ltd	Injection	785
NE21-056-06-W4	PanCanadian Petroleum Ltd	Injection	300
NE21-056-06-W4	Amoco Canada Petroleum Co Ltd	Injection	894
NW17-056-05-W4	Green Acres Sod Farms	Irrigation	106
NE23-056-05-W4	Murphy Oil Co Ltd	Injection	2272
NW23-056-05-W4	Can Salt Co Ltd	Industrial	2700
NW23-055-05-W4	Can Salt Co Ltd	Industrial	7060
SW22-055-04-W4	City of St. Paul	Domestic	5
NW25-053-01-W4	City of Lloydminster	Urban Water Supply	9000

Before modelling could be undertaken, the maximum values, as well as the arithmetic and geometric means, were calculated from the concentrations of chemicals detected in the various samples (Tables 19, 20 and 21).

The results from the UNSTOC model configured as outlined above represents basically a simple dilution process and are summarized in Table 19. The model assumes no lateral or

longitudinal mixing, that is, a point source is mixed instantly across the river. However, this assumption is not valid since dye studies indicate that the mixing zone downstream of Edmonton is about 80 km.

Using the MULTI model for a river discharge of 76 m^3 s^{-1}, with the spill duration set at 4 hours and river cross-section divided into 5 channel sections, simulations of benzene, methyl ethyl ketone, phenol, polycyclic aromatics and TOC concentrations down river were calculated. The simulation for benzene is presented in Figure 4. In addition, simulations for TOC and methylethylketone concentrations at Vinca (55 km downstream from the industrial site) were performed to show the cross-sectional river profiles. The simulation for TOC is presented in Figure 5). These toxicant concentrations are not evenly spread across the river at Vinca. Thus, contaminant concentration varies from one shore to the other.

Estimates of levels of pollutants in fish as a result of exposure to the discharged contaminants can be determined from the product of the BCF and the concentrations predicted by environmental fate modelling (Table 22).

Table 19 Maxima, arithmetic and geometric means of chemical concentrations reported in groundwater from Wells #3, #6 and #9.

Chemical	Concentration (ppm)		
	Maximum	Arithmetic Mean	Geometric Mean
Acetic acid	3,600	1,390	579
Benzene	0.14	0.035	0.015
n-Butanol	1.3	1.033	1.017
Butyric acid	230	164	153
Ethylbenzene	0.025	0.009	0.003
Isobutyric acid	240	86	26.9
Isopropanol	1.5	1.100	1.067
Methyl ethyl ketone	5.2	2.333	1.615
Propionic acid	1,100	497	343
Toluene	0.037	0.014	0.015
Xylenes	<0.025	0.009	0.003
Total Dissolved Solids	11,300	6,986	921
Total Organic Carbon	15,100	12,037	11,764

Table 20 Maxima, arithmetic and geometric means of chemical concentrations reported in sand and gravel.

Chemical	Concentration (ppm)		
	Maximum	Arithmetic Mean	Geometric Mean
Acetaldehyde	2.0	2.0	
Acetone	12.6	6.6	2.7
Aliphatic & Acyclic Hydrocarbons	3,000	798	151
Aliphatic ethers	15.0	15.0	
Aromatic heterocyclics	650	650	
Benzene	24.0	4.6	0.5
Benzo(a)anthracene	5.0	1.6	1.2
Benzthiazole	100.0	53.4	7.8
Bis(2-ethylhexyl)phthalate	5.0	1.6	1.2
Dibutylphthalate	0.9	0.8	0.3
2,4-Dichlorophenoxyacetic acid	0.2	0.04	0.05
Dimethoxymethane	17.8	9.2	3.3
Fluoranthene	5.0	1.6	1.2
Heterocyclic aromatics	350.0	96.0	17.6
Isopropanol	0.7	0.7	
3-Methyl-2-butanol	0.4	0.4	
Methyl butyl ketone	1.0	1.0	
Methyl ethyl ketone	0.8	0.8	0.8
Methyl isobutyl ketone	5.4	2.8	1.0
Methyl propyl ketone	0.0	0.0	
2-Methyl-2-propanol	0.4	0.4	
Naphthalene	5.0	2.1	0.7
Phenanthrene	5.0	2.1	0.7
Phenol	500.0	163.1	12.5
Phenolics	40.0	13.9	2.6
Picloram	0.1	0.02	0.07
Polycyclic aromatics	200.0	55.4	12.2
Substituted benzenes	130.0	44.9	11.8
Tetrahydrofuran	0.6	0.6	
Unresolved aliphatic/aromatics	750.0	550.0	522.0

Table 21 Maxima, arithmetic and geometric means of chemical concentrations detected at seepage site #7.

Chemical	Concentration (ppm)		
	Maximum	Arithmetic Mean	Geometric mean
Acetaldehyde	0.4	*	*
Acetic acid	37	*	*
Acetone	1.7	2.35	2.26
Benzene	0.13	0.084	0.069
n-Butanol	<1	*	*
Butyric acid	54	*	*
Chloroform	0.001	*	*
Dimethoxymethane	2.4	*	*
Ethyl acetate	10.5	*	*
Ethylbenzene	0.005	*	*
Ethyl propionate	0.35	*	*
Isobutyric acid	<10	*	*
Isopropanol	<1	*	*
Methyl acetate	1.3	*	*
Methyl butanoate	0.3	*	*
Methyl ethyl ketone	30	23.5	4.12
Methyl isobutyl ketone	0.8	*	*
Propionic acid	96	*	*
Toluene	0.018	*	*
Total Dissolved Solids	1,700	*	*
Xylenes	0.004	*	*

*Only one concentration reported.

Table 22 Theoretical downstream chemical concentrations calculated by the UNSTOC program.

Chemical	Celanese	North Saskatchewan River		
		76	113	339
Arsenic	0.086	1.0e-05[1]	6.7e-06	2.2e-06
Barium	1.105	1.3e-04	8.6e-05	2.9e-05
Benzene	0.13	1.5e-05	1.0e-05	3.0e-06
Benzo(a)anthracene	0.005	6.0e-07	4.0e-07	1.0e-07
Bis(2-ethylhexyl)-phthalate	0.004	5.0e-07	3.0e-07	1.0e-07
Cadmium	0.001	1.0e-07	8.0e-08	3.0e-08
Chloroform	0.001	1.0e-07	8.0e-08	3.0e-08
2,4-Dichlorophenoxy-acetic acid	0.16	1.9e-05	1.3e-05	4.0e-06
Ethylbenzene	0.005	6.0e-07	4.0e-07	1.0e-07
Lead	0.072	8.4e-06	5.6e-06	1.9e-06
Methyl ethyl ketone	30	3.5e-03	2.3e-03	7.8e-04
Phenol	0.33	4.0e-05	2.6e-05	9.0e-06
Polycyclic aromatics	0.25	3.0e-05	2.0e-05	7.0e-06
TOC	15.1	1.8e-03	1.2e-03	4.0e-04
Toluene	0.37	4.0e-05	2.9e-05	1.0e-05

[1]e denotes power of 10. For example, 1.0e-05 means 1.0×10^{-5} or 0.00001.

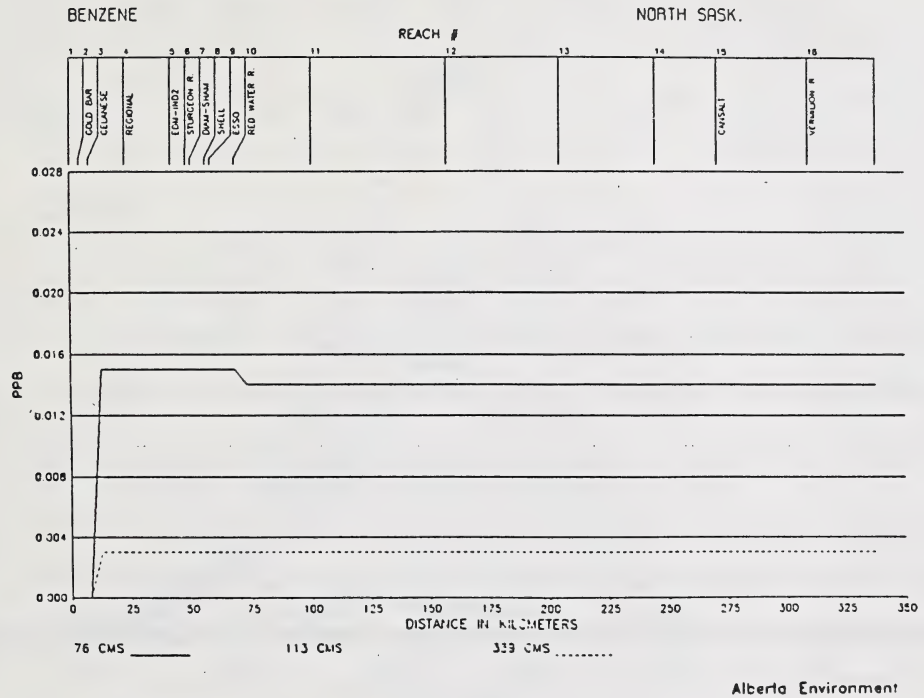

Figure 8 Theoretical downstream concentration (ppb) of benzene using MULTI model.

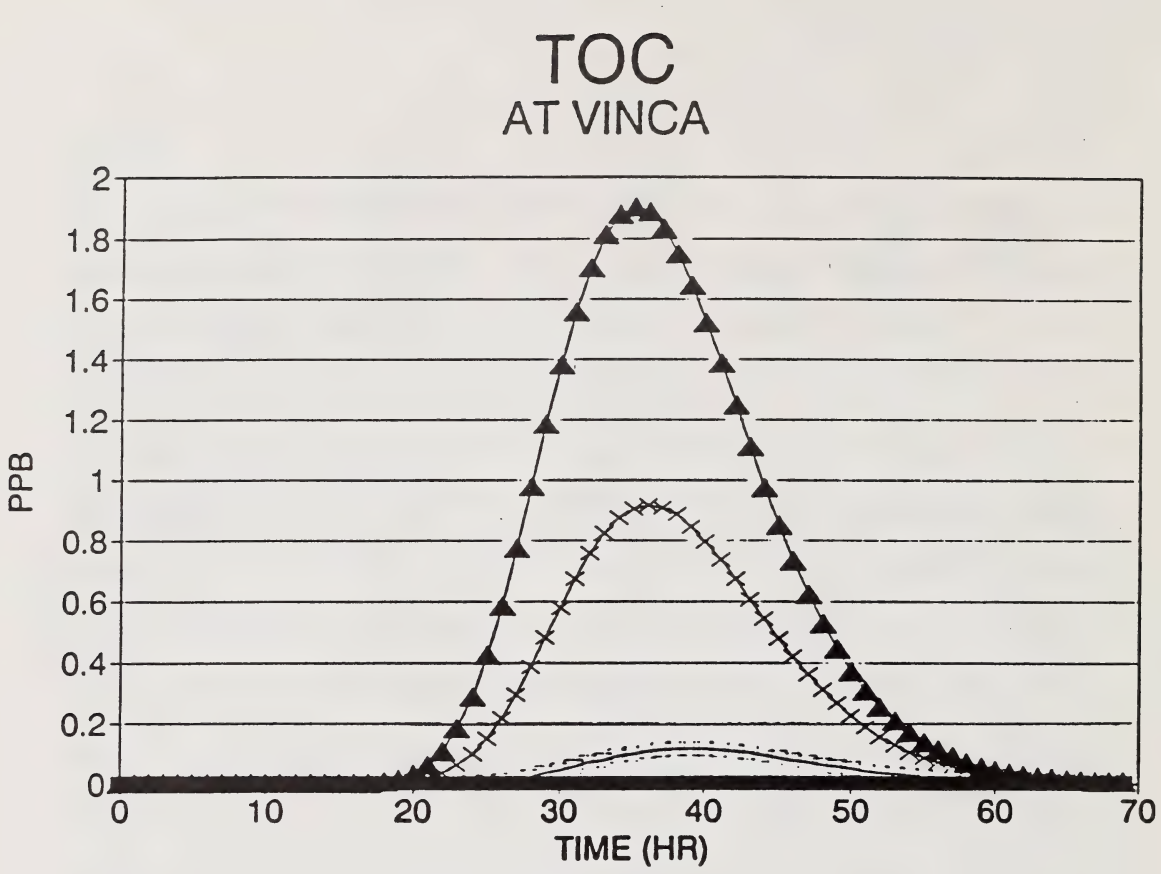

Figure 9 Theoretical river cross-section concentrations (ppb) of TOC at Vinca using MULTI model.

5 POTENTIAL BIOLOGICAL EFFECTS

Question to be asked:

What are the potential effects of the chemicals on people and animals?

The potential effects of any chemical on people and animals are exhibited only after ingestion, inhalation or dermal contact. That is, there must be contact between chemical and receptor in order for the effect to be expressed. There are three components in determining the probability of this occurrence: exposure, potency and susceptibility (Krewski, 1987).

5.1 Exposure

The amount of chemical and the route of exposure are necessary information for the quantification and evaluation of the potential dose received under the exposure conditions (Turturro and Hart, 1987; U.S. Environmental Protection Agency, 1987d). The exposure pathway can be considered to have four major elements (U.S.Environmental Protection Agency, 1986b). These are:

a. a source and mechanisms of release to the environment,

b. an environmental transport medium, for example, groundwater, air,

c. a point of potential human contact with the contaminated medium - this is the "exposure point",

d. a human exposure route at the contact point, for example, skin contact or drinking contaminated water.

Obviously, several exposure pathways exist for this site, namely, ingestion, inhalation and dermal contact.

Question to be asked: Where is the contamination located?

The contaminating chemicals are in the groundwater under the Celanese site and adjacent properties. Can it be assumed that the associated sands and gravels are also contaminated? Do the groundwaters flow through the aquifer?

Question to be asked: What are the concentrations present?

Concentrations of detected chemicals have been listed in Tables 3 through 14 and Total Organic Carbon values in groundwaters summarized in Table 16.

Question to be asked: How long have the chemicals been at the site?

From previous studies (Hardy Associates (1878) Ltd., 1982; *Ibid*, 1986) chemicals have been present in the groundwaters for at least 8 years.

Question to be asked:

What are the pathways of dispersion in the air, surface water, land, groundwater and biota?

The pathways of dispersion include:

5.1.1 Water

Contaminated groundwaters are presumed to be moving off-site into the North Saskatchewan River. There are a number of licensed users of this water within Alberta, from the industrial site to the Alberta-Saskatchewan border (Table 18).

The site of concern is located in a groundwater recharge area. Recharge water, which includes trapped water from the plant area, moves vertically and is either trapped over low permeability layers in the lacustrine deposits or in sand lenses in the till to form perched water tables or moves downwards to the permanent water table established in the sand and gravel unit (the major aquifer). Groundwater in the sand and gravel unit tends to move laterally, essentially in two directions. One flow component is west toward the North Saskatchewan River and the other is north/northwest also toward the river. Springs and seepages have been identified in the river bank west of Celanese. These features are probably surface manifestations of perched water table conditions (Ceroici, 1990; Hardy Associates (1978) Ltd., 1982a; *Ibid*, 1982b; *Ibid*, 1982c). Seepages at sites #7 and #8 are currently being retained on the industrial site.

5.1.2 Sands and Gravels

These have moved off-site (Table 23) from the commercial operation of Clover Bar Sand and Gravel Ltd. (at Keltie Farm) to industrial, commercial and residential construction projects, house renovations, sandpits, and other uses. Current usage may be limited to industrial projects.

Table 23 Off-sales from Clover Bar Sand and Gravel Ltd. (Slavinski, 1990).

Product	Off-sales (yd^3)		
	1988	1989	1990 (6/30)
Screened sand	53,000	68,000	52,000
Crushed gravel 3/4 in[1]		166,000	
Crushed gravel 3 in[1]		45,000	
Pit run		15,000	

[1] Washed before leaving the site.

5.1.3 Air

There is anecdotal information that workers drilling on-site have been nauseated following inhalation of materials venting from the drill cores. Odour was reported during a recent inspection. Workers at Clover Bar Sand and Gravel Ltd. have complained about odours in the past.

5.1.4 Biota

Fish and other biota in the North Saskatchewan River will be exposed to the contaminated groundwaters entering the river.

Question to be asked: How accessible is the contaminated site?

Access to the Celanese site is controlled by the security staff at the Main Gate. However, unauthorized access onto the site would be possible by avoiding this entry point. The sand and gravel lenses are being extracted and sold off-site through the commercial operations of Clover Bar Sand and Gravel Ltd. Access to seepages would be possible via water craft.

5.2 Potency

Question to be asked:

What are the physico-chemical characteristics of the toxicants of interest?

Identified chemical categories include acids, bases, alkylbenzenes, phenols, salts, metals, organic solvents, proprietary compounds and mixtures, *et cetera* (Tables 4 through 16).

Question to be asked:

What is the biological reactivity of these chemicals?

It is possible to determine from the literature the biological reactivity for some of the individual chemicals detected in the contaminated groundwaters, sands and gravels. The amount of information available, and its usefulness for this purpose, varies between chemicals. It is important to be aware that the biological activity of individual chemicals in a mixture may well be modified by the other chemicals present in the mixture. This confounds the predictive process of estimating the overall biological reactivity of any complex mixture. The biological reactivity of individual chemicals in a mixture may be modified by other chemicals present in the mixture by one of four categories of modifying interactions:

additive: the activity of the mixture is the simple arithmetic sum of the individual activities, e.g. 2 + 3 = 5;

synergistic: the activity of the mixture is enhanced, it is greater than the sum of the individual activities, e.g. 2 + 3 = 20;

potentiation: a constituent having no biological activity is "activated" by other chemicals in the mixture so that the total activity is greater than expected from sum of the individual activities, e.g. 0 + 2 = 10;

antagonism: the activity of the constituents decrease the expected total activity of the mixture, e.g. 4 + (-4) = 0 (simple antagonism), 4 + 0 = 1 (reverse of potentiation), 4 + 6 = 8.

It is rarely possible to predict this interactive effect. This confounds the *predictive* toxicological evaluation of complex mixtures. The toxicological properties of complex mixtures must be determined by other methods, for example, experimentation or epidemiology.

5.3 Susceptibility

Question to be asked:

What are the species, size and demographic, occupational, cultural and spatial characteristics of the populations at risk?

Several at-risk populations have been identified:

* workers at Clover Bar Sand and Gravel Ltd. and Celanese Canada Inc.,
* off-site users of the products from Clover Bar Sand and Gravel Ltd., including construction workers, professional and amateur house and garden renovators, children in

sandpits, people who may be exposed by dermal contact or inhalation of out-gassing chemicals from sands and gravels,

* downstream industrial, agricultural and domestic users of water from the North Saskatchewan River,
* biota, including fish, in the North Saskatchewan River,
* people and animals eating fish caught in the North Saskatchewan River that may have been exposed to the contaminated groundwaters.

Question to be asked:

For how long have they been affected?

Celanese Canada Inc. has been in operation since 1953. Other companies have also operated in the area for many years, for example, Monsanto Canada Inc., Uniroyal Chemical Ltd., and Rheem Canada Ltd., and Western Mines Branch, Alberta Research Council. It is possible that the populations at risk have been exposed to the chemicals listed in Table 1 since that time, albeit in altering amounts and mixtures.

6 RISK ASSESSMENT

The goal of risk assessment is to estimate the likelihood of an adverse effect on people posed by a specific level of exposure to a chemical or a mixture of chemicals. Risk management is the process of evaluating alternative actions and selecting among them. The analytical results given in Chapter 3, together with the environmental fate modelling in Chapter 4 and the identification of potential biological effects on people and animals, provide the basis for the risk assessment calculations.

Risk assessment procedures for contaminated industrial and commercial sites are highly variable. The U.S. Environmental Protection Agency has an accepted framework for evaluation of toxic waste sites as part of their Superfund program. The details are described in the various manuals pertaining to Superfund (U.S. Environmental Protection Agency, 1987d, 1989b, 1989c). *Use of this procedure does not imply that the site under investigation is to be regarded as a toxic waste site under the terms of Superfund.*

It must be emphasized that this risk assessment process for this industrial site **cannot** be reduced to a *de minimis* simplistic procedure, so to do would be to *reductio ad absurdum.* This is because, in part, there is no current evaluation procedure fully or universally accepted by scientists and regulators. Also, some important chemical data may be unavailable, both for individual chemicals and for mixtures of chemicals. Thus professional scientific judgement must play a major role in such evaluations.

There are a number of factors which may influence the process and, of course, the effort required for completion of the risk assessment process. In addition to factors pertaining to a specific site, there are those related to the degree of information or precision required for regulatory decision.

These factors include the following:

- number and identity of chemicals present,
- availability of appropriate regulatory standards and toxicity data,
- number and complexity of exposure pathways,
- necessity for precision of results, which depends upon site conditions such as estimated contaminant migration, characteristics and size of potentially exposed populations,
- quality, quantity and availability of monitoring data.

With increasing levels of complexity there is a corresponding increased level of effort required. The effort required to develop a plan for action for this industrial site, to meet with the two industrial companies, to collect and analyze samples, to analyze the data, search databases, review findings, and generate this report approximates the middle of the spectrum for this type of activity (U.S. Environmental Protection Agency, 1987d).

Qualitative risk assessment involves a simple comparison of the amount of the chemical which exists, or is expected to exist, in the environment with what is considered to be a "safe" level. It *must* be remembered that there is no "safe" level in the absolute sense. Quantitative risk assessment is usually stated in terms of the largest number of people within a specific population for whom there is the potential to be adversely affected. Because of the inherent uncertainties involved in the calculation of risk (Wilson, 1986; Finkel, 1989) the general approach adopted for this report was to calculate four theoretical exposure scenarios.

6.1 Exposure Scenarios

Scenarios were selected to represent three levels of exposure to contaminated matrices either on-site or off-site and one downstream off-site exposure:

a. *Maximum exposure*, or "worst case", represented by the highest concentration of any detected chemical contaminant, regardless of medium. That is, no difference was made between groundwater, sand or gravel. It was assumed that groundwater could contaminate the other media.

b. *Medium exposure* was based on the arithmetic mean concentration of detected chemicals.

c. *Low exposure* was based on the geometric mean concentration of detected chemicals.

d. *Downstream exposure* was based on the calculated concentrations from environmental modelling of pollutants in the North Saskatchewan River.

The maximum concentrations were used to develop the *worst case* scenario. The arithmetic mean concentrations represent the more probable higher exposure concentrations for the *medium exposure* scenario. The geometric mean represents the most probable exposure for the *low exposure* scenario. It should be noted that the geometric mean better represents the probable exposure concentration when the constituent concentrations of various samples vary considerably (Rappaport and Selvin, 1987).

6.2 Extra Lifetime Risk

It is very difficult to quantify the lifetime extra risk for many of the potential adverse effects that might be caused by one or more of the detected chemicals. The potential for induction of neoplasia (cancer) is one of the few adverse effects for which there a sufficient information base to make such calculations.

Briefly, the process has three phases:

a. Determining how target organisms (whether people or animals) might come into contact with the contaminant. Then calculating exposure values or the Lifetime Average Daily Exposure (LADE) (U.S. Environmental Protection Agency, 1989a) based either on the results of chemical analysis or from environmental fate modelling.

b. The LADE values are used to calculate the individual potential risks to people and animals (Anderson, 1983). This step is contingent upon the availability and quality of information about the toxicological effects of specific chemicals.

c. The individual risk values are combined into a single overall risk value, albeit of considerable uncertainty.

Step one is computational. The LADE value is the product of the chemical concentration (for example, mg L^{-1}), intake (for example, L d^{-1}) and duration of exposure. This is divided by the product of body weight (kg) and lifetime (days). This yields the exposure in terms of mg kg^{-1} d^{-1}. The equivalent animal dose can be calculated from this by assuming that any dose expressed in terms of surface area, for example mg m^{-2} d^{-1} is equivalent for people and animals. These values are then fitted with biological data to obtain the dose-response (step two). It is assumed in this report that the dependence of incidence of cancer is proportional to the dose level, that is, the LADE values. Many agencies use a multistage model for the calculation or risk. The combined risk (step three) has been made assuming simple addition of individual risks.

6.3 Formulae

Several equations were to calculate exposures (U.S. Environmental Protection Agency, 1989b). These formulae are helpful in establishing possible ranges of absorption of chemicals via different routes of exposure. Again, it must be stressed that an unknown degree of uncertainty surrounds each number generated. The formula used for ingestion of chemicals in drinking water was:

$$Intake\ (mg\ kg^{-1}\ d^{-1}) = \frac{CW \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

Where:

CW = Chemical Concentration in Water (mg L^{-1})

IR = Ingestion Rate (L d^{-1})

EF = Exposure Frequency (events y^{-1})

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged - days)

The equation used for ingestion of chemicals in fish was:

$$Intake\ (mg\ kg^{-1}\ d^{-1}) = \frac{CS \times IR \times CF \times FI \times EF \times ED}{BW \times AT} \quad (2)$$

Where:

CS = Chemical Concentration in fish (mg kg^{-1})

IR = Ingestion Rate (kg per meal)

CF = Conversion Factor (10^{-6} kg mg^{-1})

FI = Fraction ingested from contaminated source (unitless)

EF = Exposure Frequency (d y^{-1})

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged in days)

The equation used for dermal exposure to chemicals in water was:

$$Absorbed\ Dose\ (mg\ kg^{-1}\ d^{-1}) = \frac{CW \times SA \times PC \times ET \times EF \times ED \times CF}{BW \times AT} \quad (3)$$

Where:

CW = Chemical Concentration in Water (mg L^{-1})

SA = Skin Surface Area available for contact (cm^2)

PC = Chemical-specific dermal Permeability Constant (cm h^{-1})

ET = Exposure Time (h d^{-1})

ED = Exposure Duration (years)

CF = Volumetric Conversion Factor for Water (1 L cm^{-2} 10^{-3})

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged - days)

The equation used for dermal exposure to chemicals in sand and gravel was:

$$\textit{Absorbed Dose } (mg\ kg^{-1}\ d^{-1}) = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT} \quad (4)$$

Where:

CS = Chemical Concentration in sand/gravel (mg kg^{-1})

CF = Conversion Factor (10^{-6} kg y^{-1})

SA = Skin surface Area available for contact (cm^2 per event)

AF = Skin to Sand/gravel Adherence Factor (mg cm^{-2})

ABS = Absorption Factor (unitless)

EF = Exposure Frequency (events y^{-1})

ED = Exposure Duration (years)

BW = Body Weight (kg)

AT = Averaging Time (period over which exposure is averaged, in days)

6.4 Assumptions

Several assumptions were made for these calculations (U.S. Environmental Protection Agency, 1989a; *Ibid*, 1989b):

a. body weight of adult to be 70 kg;

b. body weight for child to be 10 kg;

c. human lifetime 75 years;

d. volume of water drunk daily 2 L;

e. amount of fish eaten daily 140 g;

f. amount of sand ingested daily by 10 kg child to be 800 mg;

g. surface area of adult hands to be 0.082 m^2;

h. work exposure to be 2 years.

6.5 Indicator Chemicals

The first step in the risk assessment process is an important one. This is the selection of indicator chemicals. Selection had three components:

a. detected organic or inorganic chemical,
b. selection of indicator chemicals,
c. availability of chemical, physical, toxicological, and fate data.

All chemicals detected and identified in any sample (Tables 4 through 16) were listed. Chemical, physical, toxicological and fate data was compiled for each identified substance on the list. An abridged summary of this compilation is presented in Table 24. Values used in subsequent risk assessment calculations were the maximum detected concentrations and arithmetic and geometric means, for:

a. groundwater from wells #3, #6 and #9 and listed in Table 19,
b. sand and gravel as listed in Table 20,
c. seepage site #7 as listed in Table 21,
d. the theoretical downstream chemical concentrations calculated by the UNSTOC program and listed in Table 22.

6.6 Organics

A number of organic chemicals were detected and the following were identified as being of most interest in the present context.

6.6.1 Benzene

Benzene is classified as a human carcinogen, Group A (Appendix C). There is sufficient evidence from epidemiological studies to support causal association between exposure and cancer. The toxicological effects of benzene include leukaemia, genetic mutation, eye and skin irritation and thrombocytopenia. Human exposure by all routes should be carefully controlled to levels consistent with animal and human experimental data. Benzene has a lower water solubility than chloroform, benzo(a)anthracene, bis(2-ethylhexyl)phthalate, methyl and phenol. It has a higher K_{OC} than chloroform, 2,4-dichlorophenoxyacetic acid, methyl ethyl ketone and phenol. Benzene has a higher fish BioConcentration Factor (BCF) than chloroform and phenol. The recommended (inhalation) exposure limit issued by the National Institute for Occupational Safety and Health (NIOSH) is 0.32 mg m^{-3} for a 10 h Time-Weighted Average (TWA), with a Short-Term Exposure

Limit (STEL) of 3.2 mg m^{-3} for 15 m (RTECS, 1990). The Threshold Limit Value (TLV) recommended by the American Conference of Governmental Industrial Hygienists is 0.3 mg m^{-3} for a 8 h TWA with no STEL (ACGIH, 1990). The Maximum Acceptable Concentration (MAC) for drinking water is 0.005 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989). TheU.S. Maximum Contaminant Level Goal (MCLG) is 0.0 mg L^{-1}. The Hazardous Products Act (1970) of Canada prohibits the import, sale, *et cetera*, of toys, goods or equipment containing more than 10 per cent w/v benzene "*...where the substance can, under reasonably foreseeable circumstances, become accessible to a child...*". There is no analytical data on airborne benzene concentrations at the industrial sites. The maximum detected concentration in water samples from wells 3, 6 and 9 was 28 times, the arithmetic mean 7 times and the geometric mean was 3 times the MAC. The oral potency for carcinogenicity is 5.20 x 10^{-2} mg kg^{-1} d^{-1}.

6.6.2 Benzo(a)anthracene

This compound is classified as a possible human carcinogen, Group B_2. The oral ED_{10} is 0.049 mg kg^{-1} d^{-1}. It has a very high K_{OC} indicating a likely high bioconcentration factor and low environmental mobility.

6.6.3 Bis(2-ethylhexyl)phthalate

This chemical is classified as a possible human carcinogen, Group B_2. Concentrated mists can cause irritation of the nose and throat, coughing, sneezing and bloody hose, dizziness, headache and nausea, and irritate the eyes. It is only slightly irritating to the skin, is poorly absorbed through the skin, and is not a skin sensitizer. Ingestion of large quantities, in the order of 10 g, result in nausea, vomiting, dizziness and diarrhoea. The Tolerable Daily Intake (TDI) is 20 µg kh^{-1}bw d^{-1}. The TLV-TWA is 5 mg m^{-3} and the STEL is 10 mg m^{-3} (ACGIH, 1989). Under WHIMS legislation it is confirmed B category and meets the criteria for disclosure at concentrations of 0.1 % or greater. The oral potency is 6.84 x 10^{-4} mg kg^{-1} d^{-1}. There is a paucity of information for environmental modelling.

6.6.4 Chloroform

This chemical is classified as a probable human carcinogen, Category B2. The chemico-physical data indicates it is quite water soluble, has a relatively low K_{OC}, a long persistence (0.3-30 days) in surface water and a fish BCF of 3.75. It has a high carcinogenic

Table 24 Physico-chemical data for selected identified chemicals.

Chemical	IS Value		Rank		Water Sol mg L^{-1}	Vapour Pressure mm Hg	Henry's Law Constant	K_{oc}	BCF	T1/2 Air (Days)		T1/2 S Water (d)	
	PC	NC	PC	NC						Low	High	Low	High
Arsenic	3.50E-01	1.55E+00	1	2		0.00			44	5			
Barium		4.51E+00		1						4.8			
Benzene	1.00E-03	1.52E-02	2	7	1.75E+03	9.52E+01	5.59E-03	83	5.2	6.00		1	6
Benzo(a)anthracene	2.91E-03		3		5.70E-03	2.20E-02	1.16E-06	1380000		5.50		0.1	5
Bis(2-ethylhexyl)phthalate	2.28E-06		5										
Chloroform	5.63E-05		4		8.20E+03	1.51E+02	2.87E-03	31	3.75	80.00		0.3	30
2,4-Dichlorophenoxyacetic acid		1.98E-02		6	6.20E+02	4.00E-01	1.88E-04	20					
Ethylbenzene		5.50E-05		9	1.52E+02	7.00E+00	6.43E-03	1100	37.5	1.46		1.5	7.5
Lead		6.43E-02		4		0.00			49	4.8		?PERS	
Methyl ethyl ketone		2.32E-01		3	2.68E+05	7.75E+01	2.74E-05	4.5	0	0.58		10	
Phenol		3.30E-02		5	9.30E+04	3.41E-01	4.54E-07	14.2	1.4	0.62	9	0.62	9
Toluene		1.92E-04		8	5.35E+02	2.81E+01	6.37E-03	300	10.7	1.30		0.17	

[1] = Indicator Species
[2] = Positive Carcinogen
[3] = Non Carcinogen
[4] = Organic Carbon Coefficient
[5] = Bio Concentration Factor
[6] = Days
[7] = e denotes power of 10, e.g., 1.0e-05 means 1.0×10^{5} or 0.00001.

potency of 8.1 x 10^{-2} mg kg^{-1} d^{-1}. The MAC for trihalomethanes is 0.35 mg L^{-1} in drinking water (Guidelines for Canadian Drinking Water Quality, 1989). The TLV-TWA is 49 mg m^{-3} (ACGIH, 1990). In addition to its tumorigenic potential, chloroform is a gastro-intestinal irritant and central nervous system depressant. It has caused rapid death attributed to cardiac arrest; and delayed death from liver and kidney damage. The probable oral lethal dose for humans is 0.5 to 5 g kg^{-1} (Chemical Emergency Preparedness Program, 1985). The Hazardous Products Act (1970) prohibits to sell, *et cetera*, without detailed labelling. The maximum detected concentration was 350 times the MAC.

6.6.5 2,4-Dichlorophenoxyacetic Acid

The evidence for human carcinogenic potential is unclear. It is less soluble in water than benzene and chloroform. The Minimum Effective Dose-Oral (MED-O) for non-carcinogenic toxicity is 1.29 x 10^2 mg d^{-1}, with a Rating Constant for non-carcinogens (Rve) (Appendix B) of 8 (organ dysfunction, neuropathies, cellular changes). An MCLG of 0.07 mg L^{-1} has been proposed in the U.S.A. The MAC is 0.1 mg L^{-1} in drinking water (Guidelines for Canadian Drinking Water Quality, 1989); the highest detected concentration was sixteen times the MAC. The Acceptable Daily Intake (ADI) is 300 µg kg^{-1}bw d^{-1}. The TLV-TWA is 10 mg m^{-3} (ACGIH, 1990), and positive cytogenetic findings have been reported in non-human bone marrow and *in vitro* human lymphocyte assays. The Food and Drugs Act (1985) prescribes limits of 2-5 mg kg^{-1} for plant items.

6.6.6 Ethylbenzene

Ethylbenzene is classified as non-carcinogenic. It is slightly less water soluble than 2,4-dichlorophenoxyacetic acid and has a K_{OC} value of 1100. The TLV-TWA is 434 mg m^{-3} and the STEL-TWA is 543 mg m^{-3} (ACGIH, 1990). The MED(O) is 7.24 x 10^2 mg d^{-1}, with an Rve of 4. The Aesthetic Objective (AO) is =<0.0024 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989); the highest detected concentration was twice the AO.

6.6.7 Methyl Ethyl Ketone

Methyl ethyl ketone is classified as non-carcinogenic and is quite soluble. The MED-O is 2.58 x 10^3 mg d^{-1}. The TLV-TWA is 590 mg m^{-3} and the STEL-TWA is 885 mg m^{-3} (ACGIH, 1990). The RVe is 10, that is, the adverse effects are severe and life shortening.

6.6.8 Phenol

This is classified as non-carcinogenic. In waters frequented by fish the Canadian limit is 1.0 ppm phenol in stormwater. The TLV-TWA is 19 mg m^{-3} (ACGIH, 1990). The MED-O is 5.98 x 10^1 mg d^{-1}, with an RVe of 3 (cellular changes, but no changes in organ weights). The U.S. permissible level for protection of freshwater aquatic life is 0.60 mg L^{-1} (24 h average) and a ceiling of 3.4 mg L^{-1}. It was one of the more water soluble organics identified in the groundwater. The probable oral lethal dose for people is 50-500 mg kg^{-1} (Gosselin *et al*, 1976). Lethal amounts may be absorbed through skin or inhaled. Industrial contact can cause chronic poisoning with kidney and liver damage (Chemical Emergency Preparedness Program, 1985). The maximum amount that can be transported by road vehicle is 5 L per package (Transportation of Dangerous Goods Act, 1985).

6.6.9 Toluene

This chemical is classified as non-carcinogenic. The TLV-TWA is 377 mg m^{-3} and the STEL-TWA is 565 mg m^{-3} (ACGIH, 1990). It has an MED-O of 2.69 x 10^3 mg d^{-1}, with an RVe of 7 (detectable decrement in organ function, measurable change in activity). The Aesthetic Objective for drinking water is =<0.024 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989); the highest detected concentration was one and a half times the AO. The maximum amount that can be transported by road vehicle is 5 L per package (Transportation of Dangerous Goods Act, 1985).

6.7 Inorganics

6.7.1 Arsenic

This element is classified as a possible human carcinogen, Category A. The TLV-TWA of 0.2 mg m^{-3} includes arsenic-containing soluble compounds (ACGIH, 1990). MED-O of 1.00 mg d^{-1}, with an RVe of 9 for non-carcinogenic effects (pronounced structural and functional changes). The MED-O is 1.50 x 10^{1} mg kg^{-1} d^{-1} and It has a fish BCF of 44. The MAC is 0.05 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989); the highest concentration detected was one and three-quarters the MAC. The maximum authorized arithmetic mean concentration is 0.5 mg L^{-1} and pH =>6.0. For a grab sample it is 1.0 mg L^{-1} and pH=>5. Arsenic may be deposited into an area frequented by fish, such as the North Saskatchewan River, as long as the above concentrations are not exceeded and the pH is not less than the level given. The Hazardous Products Act (1970) prohibits the import, sale, *et cetera*, of toys, goods, equipment and other products for use by the child in learning or play containing more than 0.1 per cent arsenic (dissolved in 5 per cent hydrochloric acid).

6.7.2 Barium

Barium is classified as a non-carcinogen. The TLV-TWA for barium and soluble compounds is 0.5 mg m^{-3} (ACGIH, 1990). The Interim Maximum Acceptable Concentration (IMAC) is 1.0 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989); the highest concentration was ten per cent above the IMAC. The MED-O is 4.90 mg d^{-1} with an RVe of 10. The Hazardous Products Act (1970) prohibits the import, sale, *et cetera*, of toys, goods, equipment and other products for use by the child in learning or play containing more than 0.1 per cent barium (dissolved in 5 per cent hydrochloric acid).

6.7.3 Lead

Lead is a possible human carcinogen, Group B_2. The TLV-TWA for lead, inorganic dusts and fumes is 0.15 mg m^{-3} (ACGIH, 1990). The MAC is 0.01 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989); the highest detected concentration was twice the MAC. Lead is not very soluble in water. It tends to adsorb to organic compounds and form complexes with naturally-occurring organics such as humic and fulvic acids. Thus it can be expected to bind to

river sediments. Lead does not tend to bioaccumulate. It can have an adverse effect on developing neural systems. The Hazardous Products Act (1970) prohibits the import, sale, *et cetera*, of toys, goods, equipment and other products for use by the child in learning or play containing more than 0.5 per cent w/w lead in the total solids. The MAC is 0.01 mg L^{-1} (Guidelines for Canadian Drinking Water Quality, 1989); the highest concentration detected was seven times the MAC.

6.8 Acceptable Daily Intakes

The Acceptable Daily Intakes (ADI) and Tolerable Daily Intakes (TDI) are listed for those chemicals detected and for which an ADI exists (Salminen, 1990) (Table 25). As can be seen, there are ADIs or TDIs for only five of the indicator chemicals.

Table 25 List of ADI/TDI for detected chemicals.

Chemical	ADI[1]	TDI[2]	Units
Bis(2-ethylhexyl)phthalate		20[3]	µg kg^{-1} bw d^{-1}
Dibutyl phthalate	18[3]		ug kg^{-1} bw d^{-1}
2,4-dichlorophenoxyacetic acid	300[4]		ug kg^{-1} bw d^{-1}
Ethyl acetate	0-25[5]		mg kg^{-1} bw d^{-1}
Picloram	70[4]		mg kg^{-1} bw d^{-1}

[1]Acceptable Daily Intake
[2]Tolerable Daily Intake
[3]Established by Health Protection Branch, Health & Welfare Canada, toxicologists
[4]Established by World Health Organization (WHO)
[5]Established by Joint Expert Committee on Food Additives, WHO

6.9 Estimated Exposures

It is possible to calculate estimates of exposure for the indicator chemicals. It should be stressed that such calculations are based on a number of assumptions and individual exposures may vary from the estimated exposure.

6.9.1 Fish Burden

The theoretical fish burden was calculated for a number of the identified chemical substances from the calculated downstream concentrations (Table 22) and the BioConcentration Factor (BCF) as depicted in Table 23. The results of these calculations are listed in Table 25.

6.9.2 Extra Lifetime Risk

The above methodologies were used to calculate the extra lifetime risk associated with exposure of an adult or child to the maximum concentration detected by analyses. Three pathways of exposure were considered: ingestion of water, ingestion of contaminated fish, and ingestion of contaminated sand and gravel (U.S. Environmental Protection Agency, 1986a). It must be stressed that these predictions are based on mathematical models. It is usual to assume the acceptable risk to be between 1×10^{-5} and 1×10^{-6}, that is, one case of cancer in 100,000 to 1,000,000 people. A frequency greater than this value, for example, 1×10^{-4} or one case in 10,000 people, is often regarded as unacceptable.

Applying the above assumptions, the risks were calculated for a small child who ingested 800 mg of sand daily whilst playing in contaminated sand (Table 27). Using a maximum exposure scenario that is probably realistic, the sum of increased risk for carcinogen is less than 1 in 1,000,000 and for non-carcinogenic activity the sum of additional risk was much less than 1 in 1,000,000. The additional risks for an adult drinking the leachate and eating contaminated fish daily for 70 years were also calculated (Table 28) This is an extreme scenario, assuming absorption of maximum concentrations. In this case the calculated additional risk was greater than 1 in 1,000,000, actually about 5 in 100. This is unlikely to occur, as is the exposure scenario.

6.9.3 Dermal

Dermal exposure is a possible route of exposure of people to the contaminating chemicals. However, there is very little published information on potential exposure conditions to calculate risk values for the inhalation and dermal pathways of exposure. Using the given equation and assuming that hands only were exposed, possible human exposure to TOC, as representing the total chemical mixture, were calculated (Table 29).

Table 26 Estimated pollutant burden in fish.

	Concentration (ppm)		
Chemical	Source: Seep 7	Source: Groundwater	Source: Downstream
Arsenic	3.78e+00[1]		4.4e-05
Benzene	6.8e-01 - 3.5e-01	7.3e-01 - 8.0e-02	7.8e-05
Lead	9.0e-02		4.1e-04
Phenols	2.6e+03 - 1.8e+-1		5.6e-05

[1]e denotes power of 10. For example, 1.0e-05 means 1.0 x 10^{-5} or 0.00001.

Table 27 Theoretical extra lifetime risk for child eating 800 mg contaminated sand daily.

	Lifetime Extra Risk	
Chemical	Carcinogen	Non-carcinogen
Arsenic	1.40e-09[1]	6.19e-09
Benzene	5.41e-07	
Benzo(a)anthracene	1.16e-11	
Chloroform	2.25e-13	
Methyl ethyl ketone		9.29e-07
Total	5.42e-07	9.35e-07

[1]e denotes power of 10. For example, 1.0e-05 means 1.0 x 10^{-5} or 0.00001.

Table 28 Theoretical extra lifetime risk from adult drinking 2 L leachate and eating 140 g contaminated fish daily.

Chemical	Extra Lifetime Risk
Arsenic	4.42e-02[1]
Benzene	1.93e-04
Methyl ethyl ketone	6.64e-03

[1]e denotes power of 10. For example, 1.0e-05 means 1.0 x 10^{-5} or 0.00001.

Table 29 Theoretical amounts of TOC absorbed dermally under three exposure scenarios.

Exposure Scenario	Amount Absorbed (mg)
Maximum	0.2
Medium	0.1
Low	0.007

6.9.4 Inhalation

There are anecdotal reports that breathing the air around a drilling core immediately after its removal from a contaminated well caused severe nausea.

6.10 Medium Exposure

The calculations for this scenario are based on the arithmetic means of identified chemicals in Tables 19, 20, and 21. In general terms the probable risk associated with the arithmetic mean of groundwater from the three wells is one-half (x 0.5) that of the maximum concentration. Similarly, the risk associated with sand/gravel is 40 per cent (x 0.4), and the risk associated with seepage site #7 is 70 per cent (x 0.7) that of the maximum concentration.

6.11 Low Exposure

The calculations for this scenario are based on the geometric means of identified chemicals in Tables 19, 20, and 21. In general terms the probable risk associated with the arithmetic mean of groundwater from the three wells is one-third (x 0.3) that of the maximum concentration. Similarly, the risk associated with sand/gravel is 20 per cent (x 0.2), and the risk associated with seepage site #7 is 30 per cent (x 0.3) that of the maximum concentration.

6.12 Downstream Exposure

The estimates derived from environmental modelling indicate that concentrations of chemicals introduced into the North Saskatchewan River would be reduced to below current guidelines and regulations.

6.13 Absorption via Different Routes of Exposure

Absorption of chemicals will differ with the various routes of exposure. This is illustrated in Table 30.

Table 30 Theoretical amounts of benzene absorbed daily from four types of exposure.

Route of Exposure	Absorbed Amount (mg)
Oral - Drinking contaminated water	0.28
Oral - Eating fish	0.05
Dermal - Water on skin	0.05
Dermal - Sand on skin	0.0004

6.14 Implications of the Theoretical Exposures

The theoretical maximum exposure values show an increase over the acceptable risk for benzene values of approximately one thousand-fold (10^3). Anecdotal information of accidental human exposures during chemical analyses of the contaminated waters suggests that dermal contact may cause skin rashes. In fact, skin rashes are the commonest human body reaction to accidental exposure to chemicals. It cannot be emphasised too strongly that these calculations contain a fair degree of uncertainty. This scenario is unrealistic, since it is unlikely that any individual would drink 2 L d^{-1} of the contaminated groundwater.

However, the implication that exposure of an adult might be associated with toxicity, affecting 1 in 25 individuals, is supported by the bioassay data (Table 17) and the related pathology findings.

The pathology findings include:

* dose-related branchial oedema,
* hypertrophy and hyperplasia of the epithelial cells lining the lamellae of the gill filaments,
* vesicle in the skin and pharynx.

These lesions indicate that contact with the leachate can initiate reversible and irreversible changes in exposed organisms. For non-aquatic animals the target tissues would be skin, mucous membranes, and the gastro-intestinal and respiratory tracts.

Although there are reports on the toxicity of some (but not all) of the constituent compounds detected in the groundwaters, there are no reports on the toxicological effects of combinations of these same constituents. The correctness of assuming that the total effect of the constituents is additive is unknown. The totality of their effects may be additive, synergistic, potentiation or antagonistic (Chapter 5.2).

Because a person or an animal will be exposed to a mixture of the constituent compounds rather than to individual and separate chemicals, this report will not catalogue in detail the individual effects of these compounds. The reported effects of the chemicals identified by chemical analysis include:

* carcinogenicity,
* hyperplasia (proliferation of cells),
* hypertrophy (swelling of cells),
* decreased organ function,
* decreased system function,
* life-shortening or death,
* skin lesions,
* reversible cell changes,
* irreversible cellular changes,
* changes in physiological, behavioural, sensory activities.

The severe acute toxic effects observed with three aquatic species prevents a facile dismissal of the contamination as harmless.

6.15 Uncertainty

It has been assumed that these theoretical exposure scenarios are valid representations. This is patently incorrect on a site by site analysis. However, it is prudent to consider these scenarios valid for two reasons:

a. Variations in groundwater flow due to meteorological changes.

b. Lack of information on detailed environmental mobility of the constituent compounds in the groundwaters.

The use of the LADE value implies, *a priori*, that variation in concentration over time is irrelevant to the calculations. The severity of changes following exposure to chemicals can vary with the age and state of development of the exposed individual. For example, foetus, newborn, infant, child, young adult, mature adult, or aged adult. Further, there can be a difference in biological response between intermittent, variable or constant exposure to toxic chemicals.

Because of the lack of time-dependent data, these variables have not been considered in the mathematical modelling process.

It has been further assumed that effect is directly a function of the administered dose, for example, that quantity ingested. In fact, biological effect can be related to the metabolized dose. The process of metabolizing the chemical may reduce, enhance or potentiate the toxic effect, or even not alter the toxic effect. Additionally, there can be changes in metabolic pathways related to low and high doses of compounds.

Extrapolation from toxic effects in animals to those that might be anticipated in people is fraught with uncertainty. Use of body weight, surface area, and basal metabolic rate, by direct extrapolation (as in this report) or by use of factoring are common methods. It has been stated that there is "*no really scientific basis for any mathematical extrapolation model*" (Anderson, 1983).

It was not possible to characterize fully the organic content of the contaminated groundwater. Between 73 and 96 per cent of the organic content is unidentified. Because the majority of the organic content was not identified, caution should be exercised before accepting individual chemical risk values or even the sum of risk values for identified chemicals as representative of the total chemical mixture. The toxicological properties of the various mixtures of ketones, alcohols, acids, *et cetera*, are unknown. The bioavailability of the unidentified contaminants is unknown.

It is constructive to recall the observations of acute toxicity in three aquatic test species (Table 17). These, or other bioassays, may be helpful as biological indicators of toxicity during the remediation process.

6.16 Summary

The predicted downstream concentrations of benzene, calculated by the UNSTOC program, were 1.5×10^{-5} (0.000015), 1.0×10^{-5} (0.00001) and 3.0×10^{-6} (0.000003) ppm at 80 km downstream of Edmonton (Table 22). These predicted values are 13 times *less* than observed values. The estimates derived from environmental modelling indicate that concentrations of chemicals introduced into the North Saskatchewan River would be reduced to below current guidelines and regulations.

Using benzene as the example, the probable risk associated with the maximum exposure scenario to groundwater shows an increase over the acceptable risk of approximately one thousand-fold (10^3). Anecdotal information of accidental human exposures during chemical analyses of the contaminated waters suggests that dermal contact may cause skin rashes. In fact, skin rashes are the commonest human body reaction to accidental exposure to chemicals. It is unlikely that any individual would drink 2 L d^{-1} of the contaminated groundwater, or ingest 800 mg sand on a daily basis.

In general terms the probable risk associated with the medium exposure scenario to groundwater from the three wells is one-half (x 0.5) that of the maximum concentration. Similarly, the risk associated with sand/gravel is 40 per cent (x 0.4), and the risk associated with seepage site #7 is 70 per cent (x 0.7) that of the maximum concentration.

Likewise, the probable risk associated with the low exposure scenario to groundwater from the three wells is one-third (x 0.3) that of the maximum concentration. Similarly, the risk associated with sand/gravel is 20 per cent (x 0.2), and the risk associated with seepage site #7 is 30 per cent (x 0.3) that of the maximum concentration.

From estimates of human exposure, it appears that the ADI or TDI for the five chemicals listed in Table 25 would not be exceeded.

7 PERCEPTIONS

Public perception of risks to health are enormously important influences in shaping both individual choices and political direction. Public policy directions for energy policies, industrial policy, as well as government regulations, are all heavily coloured by the electorate's views towards risks (Burger, 1988).

Dutch researchers identified four qualitatively different response patterns among residents of a heavily industrialized area. In increasing order of manifest anxiety as evidenced during interviews, the types were Secure, Accepting, Defensive, and Vigilant. The authors concluded that anxiety was a function of risk assessment conducted by the residents, and was proportional to the opportunities for personal control (specific) and of hope (general) to bringing about a better environment by one's own actions (Stallen and Tomas, 1988).

It cannot be denied that potential human carcinogens are present in the groundwater and, by implication, in every structure they contact. Whether or not exposure of an individual to one or more of these possible human carcinogens, or other toxic compounds, present in the groundwater, actually poses a threat is not the issue. The public perception will likely be that such exposure is not acceptable. Exposures ensuing from contact with the contaminated groundwaters or associated structures is *involuntary*, that is, individuals *did not choose to be exposed.* Whether such exposures imply a greater or lesser risk to health than smoking is irrelevant, for smoking is a *voluntary* risk - at least for the smoker.

The popularity of the current trend toward the "greening" of the environment is also a factor in the perception of this present issue.

8 SUMMATION

Briefly, the situation at the two industrial sites is that contaminated groundwaters are discharging into the North Saskatchewan River and affecting a commercial sand and gravel operation. The river is accessed downstream for potable water.

Several contaminants, including arsenic, benzene, and lead, have been detected in on-site areas. The putative sources of the chemical contamination are the capped waste disposal lagoons on the industrial site. Apparently, these may have received waste chemicals from adjacent industrial operations. Contaminants are migrating from the site to off-site areas through the groundwater and possibly from a commercial sand and gravel operation.

The groundwater flow has been estimated at 420 L min^{-1} with an average Total Organic Carbon (TOC) content of approximately 12,000 mg L^{-1} (ppm). This suggests a daily discharge of approximately 7,300 kg d^{-1} into the North Saskatchewan River, or some 7.3 long tons daily. This assumes that the seepages were contained.

8.1 Concerns

There are concerns for the adverse ecological and health effects of chemicals moving off-site via the North Saskatchewan River and via sand and gravel sales.

8.2 Risk Assessment

Be it said that risk assessment is not a precise process. Risk assessment deals in probabilities not certainties. It must be recognized that there is no such thing as "safe" or "risk free". The reader is reminded of the words of Paracelsus (1493-1541):

"All substances are poisons; there is none which is not a poison.

The right dose differentiates a poison and a remedy."

Only 4 to 27 per cent of the Total Organic Carbon (TOC) content was identified chemically. Discharge concentrations of some contaminants exceed Maximum Acceptable Concentrations (MAC); aquatic bioassays indicate high lethality. The calculated concentrations 55 km downstream are within MAC's for oral consumption. Due to the high percentage of unidentified content, the risk associated with exposure, e.g. to contaminated sand, is problematic; some individuals should probably be expected to reactive adversely following exposure.

8.3 Information Gaps

Question to be asked:

What is it necessary to know specifically about the situation so that a control strategy can be designed and implemented?

Information is needed about the consequences of each option in terms of the basic questions raised:

a. Identifying the type and extent of contamination by chemical analyses and biological assays.

b. Identifying and implementing feasible reclamation strategies.

c. Developing a non-site-specific process for contaminated industrial and other sites.

A further set of questions may well be developed as action plans are developed. These address costs (dollars, person-years, capital, equipment, monitoring, enforcement, compensation, reclamation, *et cetera*), feasibility, economic risks and gains, project management, contractors, *et cetera.*

Question to be asked:

Are there gaps in the available information?

Answering information gaps is not an essential prerequisite to future action concerning this industrial site. It should be noted that there are a number of areas where additional information would be helpful. These are listed below by subject areas in alphabetical order, together with examples of typical questions:

8.4 Comparison to Other Sites

a. Comparison of groundwater discharge burden to other industrial sites.

b. Comparison of river burden to other locations.

8.5 Ecology

a. Ecological effects of the various discharges on the North Saskatchewan River.

8.6 Hydrogeology

a. Variations in groundwater flow by time, season, and direction.

b. Verification of source(s) of the contaminated groundwater.

c. Documentation of the present hydrogeological status of the two sites.

8.7 Occupational and Environmental Health

a. Information concerning worker complaints and injuries.

b. Information concerning non-worker complaints.

8.8 Toxicology

a. Better estimates of human exposure via the dermal route of exposure to contaminated groundwaters, sands and gravels.

b. Better estimates of human exposure via the inhalation route to off-gassing chemicals.

c. Dermal and inhalation toxicological characterization of the complex mixtures.

d. Quantification of dermal toxicity and out-gassing of chemicals.

c. Determination of removal efficiency of adsorbed chemicals during the processing of sand and gravel.

8.9 Conclusions

The information gathered for this report represents a "snapshot" description of the site. The data represents a particular time and provides no information about current rates of change or present variations in concentrations. In addition, there are many limitations to the risk assessment process. These are confounded by the complex mixture of chemicals presented in the groundwaters. However, the following conclusions can be drawn from the available information. These are presented together with possible responses.

8.9.1 Discharge of Contaminated Groundwaters

The discharge of contaminated groundwater from this industrial site can be expected to continue for several years. Assuming the rate of discharge of TOC continues to decline in linear fashion at the same rate as for the past eight years, the contaminated discharge may continue for up to 25 years, according to the equation below.

$$Y = (X \times 670.1) + 1348457 \quad (5)$$

The rate of discharge may well not be linear. However, this approach does suggest that the TOC content will approach zero during the first quarter of the new century.

It is interesting to note that the theoretical discharge of 7,300 kg d^1 TOC into the North Saskatchewan River is approximately three times that for the Edmonton Goldbar Sewage Treatment Plant (Table 31) (Livingstone, 1990).

Table 31 Summary of mass loadings of Total Organic Carbon (TOC) of discharges to the North Saskatchewan River.

Industry	TOC kg d^{-1}
Edmonton Goldbar Sewage Treatment	>2500
PetroCanada Refinery	57
Imperial Oil Refinery	112
Fibreglass Canada	10
Sherritt Gordon	230
Celanese Groundwater Well Water	7300

CONCLUSION #1:

Discharge of contaminated groundwaters will persist for many years.

POSSIBLE RESPONSES:

* *Monitor groundwater and seepage flow, TOC content, and sources on a more frequent basis.*
* *Confirm the hydrogeological status, including verification of sources.*
* *Obtain seasonal information.*
* *Verify actual discharge concentrations into the North Saskatchewan River.*

8.9.2 Persistence of Contaminated Sand and Gravel

Persistence depends upon the degree of adsorption of chemicals onto sand and gravel surfaces and their removal by leaching and industrial processes. Decontamination of the

groundwaters, sands and gravels will be hampered by the continuing egress of toxic materials. It is with apprehension that it is noted that only some 4 to 27 per cent of the chemical contamination has been identified.

CONCLUSION #2:

Contamination of sand and gravel is correlated with contaminated groundwaters and adsorption and release. Such contamination will affect off-site usage.

POSSIBLE RESPONSES:

* *Analyze the sands and gravels for adsorbed chemicals, before and after industrial processing, using techniques that allow identification and quantitation of volatiles and water organic extractable, as well as bioassays.*
* *Examine sand and gravel for adsorbed materials by electron microscopy.*
* *Determine final utilization or disposal scenario of processed sands and gravels for various industrial, commercial, and residential applications*
* *Determine does due to occupational exposures.*
* *Investigate possible decontamination procedures, should these be required.*

8.9.3 Source of Some of the Contaminating Chemicals

The presence of 2,4-D raises the question of the origin or origins of the contamination. Was it from previous manufacture adjacent to the Celanese site, or by local application as a herbicide? When was the integrity of the deep well injection operation last checked for leaks?

CONCLUSION #3:

Not all chemicals identified in the groundwaters may have originated from waste materials from the Celanese operation.

RESPONSE:

* *Verify the movement of groundwaters and potential origin(s) of non-site chemicals.*
* *Verify integrity of deep well injection process.*

* *Ascertain the TOC and chemical loadings of the 'headwaters' of the groundwater flow through the industrial site.*

8.9.4 Probability of Exposure of People and Animals to Potential Human Carcinogens, Known Toxic Chemicals, and Other Unknown Chemical Pollutants

The presence of potential human carcinogens, toxic and potentially toxic chemicals presents an *involuntary* risk to exposed people and animals. It is unlikely that the general public would receive this information with equanimity. There is a potential for exposure of people and animals to be exposed to possible human carcinogens, toxic or potentially toxic chemicals originating from the industrial site. These exposures may be at the workplace or away from the workplace. Such exposure may enhance risk to human and animal health. Between 4 and 27 per cent of the contamination has been identified chemically. Some of the exposures could occur under unusual or uncontrolled conditions.

It should be noted that theoretical environmental fate modelling indicates that downstream concentrations are below MAC and other guidelines. For example, the predicted concentration for benzene is 1×10^{-2} the MAC, for arsenic 5×10^{-3}, for lead 1.2×10^{-3} and for phenols 1.5×10^{-4} the MAC or other guidelines.

The gill lesions identified in the fish bioassays were sufficient to block the transfer of gases, causing the fish to suffocate. The Fisheries Act (Section 33(2)) specifically prohibits the deposit of a "deleterious substance" into waters frequented by fish. This restriction applies to both the Crown and to private citizens and companies. The Clean Water Act (Section 17(1)) prohibits the deposit of a contaminant that would render water "harmful...to fish". Section 17(2) provides exceptions to Section 17(1).

CONCLUSION #4:

<u>Known and suspected human carcinogens and toxic chemicals are being discharged into the North Saskatchewan River.</u>

POSSIBLE RESPONSE:

* *Confirm the legal requirements pertinent to the contaminated discharges and apply actions as applicable.*
* *Compare risks associated with the chemical contamination to everyday risks.*

* *Request input from Alberta Health and Edmonton Board of Health*

8.9.5 Ecological Effects on North Saskatchewan River

This report has not addressed possible ecological effects of the contaminated discharges on the North Saskatchewan River. It might be difficult to attribute effects to particular industrial sources.

CONCLUSION #5:

The effects of contaminated discharge on the North Saskatchewan River have not been investigated as part of the risk assessment process.

RESPONSE:

* *Determine the effectiveness and feasibility of a small-scale study to establish the ecological effects of the contaminated discharges on the North Saskatchewan River.*

8.9.6 Toxicity of the Complex Mixtures

It is difficult to either describe complex chemical mixtures in quantitative and qualitative terms, or to assess their biological, chemical and toxicological interactions. In general, the toxicity, or potential toxicity, of complex chemical mixtures is of increasing concern in toxicology and risk assessment. Of necessity, such investigations must contain many more co-variables than would be permissible in the assessment of a single chemical.

CONCLUSION #6:

Toxicological risk assessment of complex chemical mixtures associated with industrial sites is less precise than that for a single compound.

RESPONSE:

* *Use bioassays to estimate overall toxicity of groundwater samples.*
* *Conduct a small-scale study of the dermal, inhalation and oral toxicity of the complex mixtures found at this industrial site*

8.9.7 Decontamination

Removal or containment of the source or sources of the contamination would shorten the period of discharge of contaminated groundwaters into the North Saskatchewan River, as well as adverse effects of the operation of Clover Bar Sand and Gravel Ltd.

CONCLUSION #7:

Persistence of the source of contamination will adversely affect all ameliorative measures, and ensures continuing discharge of contaminated groundwaters and seepages.

RESPONSE:

* *Develop risk management options.*
* *Remove from the site the contaminated soils and other materials acting as the source(s) of the contamination.*
* *Consider disposal by the Alberta Special Waste Management Corporation.*
* *Investigate feasibility of blocking groundwater flow.*
* *Evaluate decontamination techniques.*

8.10 Finale

"Life is the art of drawing sufficient conclusions from insufficient premises."

SAMUEL BUTLER

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Appendix A - Glossary of Terms

APPENDIX A: Glossary of Terms

Term	Explanation
ADI	Acceptable Daily Intake of a particular substance by a person
Additive	The activity of the mixture is the simple arithmetic sum of the individual activities, e.g. 2 + 3 = 5;
Antagonism	The activity of the constituents decrease the expected total activity of the mixture, e.g. 4 + (-4) = 0 (simple antagonism), 4 + 0 = 1 (reverse of potentiation), 4 + 6 = 8.
AO	Aesthetic Objective for water quality
Aquifer	Water-bearing stratum of permeable rock, sand or gravel
Arithmetic mean	Sum of values divided by number of values.
Atrophy	Diminution in size of cell, tissue, organ, or part of body.
BCF	BioConcentration Factor. Indicator of degree of concentration of chemicals by living organisms
Bioassay	Determination of the activity of a substance by noting its effect on a living organism or preparation.
Biota	The combined flora and fauna of a particular area
Branchial oedema	Oedema of the gills of fish
Carcinogenicity	The tendency or ability to produce carcinoma, or more generally, tumours
d^{-1}	Per day
e	Power of 10. For example, 1.0e-05 represents 1.0×10^{-5} or 0.00001
ED_{10}	That dose which is has effect on ten per cent of the dosed population
Enzyme induction	Increase of activity of enzyme
Epithelial cells	Cells covering the internal and external surfaces of the body, including blood vessels and cavities
Extra Lifetime Risk	Additional risk of injury (cancer) as a result of specific exposure
Geometric mean	The product of *n* values to the *n*th root
Hazard	The potential for injury inherent in the physico-chemical properties of specific compound or mixture of compounds
Hyperplasia	The abnormal multiplication or increase in the number of normal cells in normal arrangement in tissue
Hypersusceptible	Abnormally increased susceptibility to poisons, infectious agents, or agents which in the normal individual are innocuous
Hypertrophy	The enlargement or overgrowth of an organ or part due to an increase in size of its constituent cells
Hyposusceptible	Greatly decreased susceptibility to poisons, infectious agents or other agents
IS	Indicator Score. Unitless score that is the product of a media-specific concentration of a chemical and the media-specific toxicity constant for that chemical

Term	Explanation
kg^{-1}	Per kilogram
K_{oc}	Octanol-water partition coefficient
LADE	Lifetime Average Daily Exposure
MAC	Maximum Acceptable Concentration
MCLG	Maximum Contaminant Level Goal
MED(O)	Minimum Effective Dose (oral route)
Metaplasia	The change in the type of adult cells in a tissue to a form which is not normal for that tissue
$mg\ L^{-1}$	Milligrams per Litre
MULTI	Water Quality Event Mathematical Model
Necrosis	Death of tissue, usually as individual cells, groups of cells, or in small localized areas
Neuropathy	Functional disturbances and/or pathological changes in the peripheral nervous system
Oral potency	Potency of chemical to cause injury. Based on published reports
Pharynx	The musculomembranous sac between the mouth and nares and the oesophagus
Potentiation	A constituent having no biological activity is "activated" by other chemicals in the mixture so that the total activity is greater than expected from sum of the individual activities, e.g. 0 + 2 = 10
Probability	The potential realization of unwanted consequences (injury, disease, or death) of an event under specific circumstances
Risk	Possibility of injury. Evaluation has two components: hazard and probability
Rve	Rating Constants for Non-Carcinogens
STEL	Short Term Exposure Limit. Usually for a maximum of 15 minutes.
Synergistic	The activity of the mixture is enhanced, it is greater than the sum of the individual activities, e.g. 2 + 3 = 20
$T_{1/2}$	Half-life
Teratogenic	Causing abnormal development and malformations in the foetus
TLV	Threshold Limit Value
TDI	Tolerable Daily Intake
Toxicity	The inherent capacity of a substance, through its chemical or physical properties, to produce injury to a living organism
TWA	Time Weighted Average
UNSTOC	Stochastic River Quality Mathematical Model
Vesicle	A blister containing fluid
Water Quality Directive	Regulatory instrument of Alberta Environment
WHIMS	Workers Health Information Management System

Appendix B - Rating Constants (RVe) for Non-Carcinogens

APPENDIX B: Rating Constants (RVe) for Non-Carcinogens

Rating Constants (RVe) for Non-Carcinogens (U.S. Environmental Protection Agency, 1986a)

Effect	Severity Rating (RVe)
Enzyme induction or other biochemical change with no pathological changes and no change in organ weights	1
Enzyme induction and subcellular proliferation or other changes in organelles but no other apparent effects	2
Hyperplasia, hypertrophy or atrophy, but no change in organ weights	3
Hyperplasia, hypertrophy or atrophy, with changes in organ weights	4
Reversible cellular changes: cloudy swelling, hydropic change, or fatty change	5
Necrosis, or metaplasia with no apparent decrement of organ function. Any neuropathy without apparent behavioural, sensory or physiological changes	6
Necrosis, atrophy, hypertrophy, or metaplasia with a detectable decrement of organ functions. Any neuropathy with a measurable change in behavioural, sensory, or physiological activity	7
Necrosis, atrophy, hypertrophy, or metaplasia with definitive organ dysfunction. Any neuropathy with gross changes in behavioural, sensory, or motor performance. Any decrease in reproductive capacity, any evidence of foetotoxicity	9
Pronounced pathological changes with severe organ dysfunction. Any neuropathy with loss of behavioural or motor control or loss of sensory ability. Reproductive dysfunction. Any teratogenic effect with maternal toxicity	9
Death or pronounced life-shortening. Any teratogenic effect without signs of maternal toxicity	10

Appendix C - EPA Weight-of-Evidence Categories for Potential Carcinogens

APPENDIX C: EPA Weight-of-evidence categories for potential carcinogens (U.S. Environmental Protection Agency, 1986a).

EPA Category	Description of Group	Description of Evidence
Group A	Human Carcinogen	Sufficient evidence from epidemiological studies to support a causal association between exposure and cancer
Group B1	Probable Human Carcinogen	Limited evidence of carcinogenicity in humans from epidemiological studies
Group B2	Probable Human Carcinogen	Sufficient evidence of carcinogenicity in animals, inadequate evidence of carcinogenicity in humans
Group C	Possible Human Carcinogen	Limited evidence of carcinogenicity in humans
Group D	Not Classified	Inadequate evidence of carcinogenicity in animals
Group E	No Evidence of Carcinogenicity in Humans	No evidence for carcinogenicity in at least two adequate animal tests or in both epidemiological and animal studies

N.L.C./B.N.C.
3 3286 50158 4045